MBS 3399E

COMMERCIALLY AVAILABLE TECHNOLOGIES FOR HAZARDOUS WASTE TREATMENTS

JANUARY 1996

Ontario

Ministry of
Environment
and Energy

ISBN 0-7778-4839-2

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PIBS 3399E

COMMERCIALLY AVAILABLE TECHNOLOGIES FOR HAZARDOUS WASTE TREATMENT

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January 1996

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APPENDIX A: APPLICATION OF WASTE TREATMENT TECHNOLOGIES FOR INORGANIC WASTES (TABLES)

APPENDIX B: APPLICATION OF WASTE TREATMENT TECHNOLOGIES FOR ORGANIC WASTES (TABLES)

EXECUTIVE SUMMARY

This report has been prepared primarily for the benefit of the MOEE staff dedicated to development, implementation and enforcement of programs related to treatment and management of hazardous wastes (as defined under Regulation 347).

The introductory chapter at the beginning of this report will hopefully introduce various concepts in hazardous waste treatment technologies, and the economics driving the cost of managing hazardous wastes.

Detail reviews of specific technologies are presented in the subsequent chapters, in separate sections. Each technology is presented in its individual module, independent of each other. This modular format will facilitate the dissemination of information on specific technologies, as requested by individual staff.

Hazardous waste treatment technologies are divided by types: physical, chemical, thermal/incineration, biological, and other miscellaneous processes. These types form the six technical chapters of the document.

The document can also be used for informing the general public, on an individual request basis.

Additional information

Numerous references and personal consultation have been used in the preparation of this report. Additional information or clarification on any issues raised in this document can be obtained from the Environmental Engineering Services Section, Science and Technology Branch, Toronto (Gilles Castonguay at 416-323-5214, or general inquiry at 416-323-5200).

1. INTRODUCTION

1.1 HOW TO USE THIS REPORT

Objective

This report has been prepared primarily for 2 audiences. Because of its technical approach, the document is addressed to front line users of technology assessment (i.e. staff from MOEE regional and district offices, and approval staff from Approvals Branch). The second target audience is for senior management reference, where conclusions in various sections and technical modules can be used for guidance in policy development and program management.

Report layout

The first section deals with general issues such as objective of the report, how the cost evaluation of each technology is done, and what are the factors to consider during the selection of technologies.

The following sections (sections 2 to 7) review and summarize in independent modules various methods of hazardous waste treatment:

- Section 2: physical treatment
- Section 3: thermal/incineration
- Section 4: chemical treatment
- Section 5: biological treatment
- Section 6: fixation/stabilization
- Section 7: miscellaneous treatment

The treatment process selected depends on the type of waste to be treated. Often, more than one technology will be required to treat a specific waste. For instance, centrifugation may be used to separate solids from a waste mixture, with the decant liquid sent for treatment in a biological treatment process and the solid portion to a fixation/stabilization process.

All the technologies identified in this document are commercially available either provincially, nationally, in North America, or in the European continent. Some emerging technologies may be identified and reviewed in the document, as a modification of a commercially available technology. The level of commercialization and availability is dependent on the level of innovation, demonstration and market demand of such technologies in North America. This information is mentioned under the heading of "applicability" in each section.

This document does not include the review of technologies for treatment of contaminated soils, which is covered in other MOEE publications (1-3). Review of technologies for treatment of groundwater (4) is also available from the Science and Technology Branch. Some technologies identified in this document can also be used for other applications in soil and groundwater treatment. Consequently these technologies may also have been reviewed in the other MOEE publications mentioned above.

References

1. MOEE, 1992. Remediation technologies for contaminated soils. October 1992. PIBS 2157. ISBN 0-7778-0323-2.

2. MOEE, 1993. Application of soil remediation technologies in the Greater Toronto Area. August 1993. PIBS 2684. ISBN 0-7778-1785-3.

3. MOEE, 1995. Site remediation technologies used in Ontario. October 1995.

4. MOEE, 1995. Treatment technologies for contaminated groundwater. A literature review. October 1995.

1.2 COST EVALUATION

Cost and price concepts (1,3)

The concepts of cost and price for setting up and operating a waste management system need to be clarified. Costs are those identifiable and accountable expenses incurred during the procurement of equipment, construction of a waste management system, operation and maintenance. Price is a result of interaction between supply and demand forces in a commercial market. The connection between the two concepts can be summarized as follows: the market price reflects the vendor's costs and the vendor's profit margin.

In this document, the evaluation of the technology cost would make more sense than looking at the price that the market is willing to bare. In most cases, the price may include a reasonable profit margin (2% to 10%). Under low competition conditions, the margin may be much higher. In poor economic and high competition conditions, the vendor may be willing to price the technology under cost for a short time. Vendors are reluctant to reveal their costs however, because it gives clues as to the economic status of their operation and of the industrial sector in general. For practical purpose in this document, we will present the cost as often as possible. If the price in indicated, an estimated profit margin will be mentioned and costs estimated.

Cost estimate level

The American Association of Cost Engineers has established 3 levels of engineering estimates:

1. order of magnitude estimate: this approach provides estimates in the +50% to -30% range, without using preliminary design work;

2. budget-level estimate: this approach provides estimates in the +30% to -15% range, using design work completed at 15-25%;

3. definitive estimate: providing estimates accurate in the +15% to -5% range, using complete engineering data.

In this document, the order of magnitude estimate will be the predominant level for the cost estimates. In some instances the cost estimate may be at the budget level for specific plants if it is reported in a report or paper.

Various costs

Various costs are considered in the evaluation of the total cost of operating a specific technology. The cost evaluation of each technology is based as much as possible on the cost estimate of each of the category identified in Table 1.2a (1). Twelve categories of costs have been identified, some of which are not applicable to permanent installations (i.e. demobilization).

1994 normalization

The capital cost for individual technology may be based on years prior to 1994. One way to normalize the capital cost to 1994 (1995 statistics are incomplete at the time of writing) is to use the Machinery and Equipment Price Index for the chemicals and chemical products sector, or for the petroleum and coal products sector (4,5). The prices used are for domestic machinery and equipment, adjusted for changes in federal sales tax. U.S. prices are adjusted for changes in exchange rates, custom tariffs and Canadian federal sales tax. The chemical and chemical products sector seems to be the most appropriate sector representing equipment used in waste treatment. The petroleum and coal products sector would be the second best. Price index from both sectors are included in Table 1.2b for comparison purposes.

In an integrated waste management system, such as the one designed by OWMC (5), equipment capital represents nearly 50% of the total cost of waste treatment.

Operating costs

The concept of annual operating costs includes various expenses incurred during the operating year. The operating costs normally include the following costs (6):

- Fixed costs:
  - Maintenance (3% of capital)
  - Administration (1.5% of capital)
  - Insurance (1% of capital)
  - Taxes (estimated)
  - Head office cost (estimated)

- Variable costs (estimated based on technology requirements):
  - Labour
  - Chemicals
  - Power
  - Fuel
  - Consumable.

Another cost normally not included in the operating costs is an annual estimated cost to cover for the capital investment in equipments and facilities. The annual charge on the capital cost varies depending on the initial evaluation assumptions: in the present case, the amortization is done over 20 years at an average interest rate of 8%, leading to an approximate annual capital rate of 13% of the initial capital. There is also the depreciation of the capital which is assumed, for simplicity, to be constant at 5% per year for an expected life of 20 years. The capital charges include:

- Cost of capital (13% of capital over 20 years);
- Depreciation cost (5% of capital per year over 20 years).

The total annual costs include the capital charges and the operating costs. The price for treatment of specific wastes will normally be based on the total annual costs and some acceptable profit margin that the market will support. Depending of the expected life of specific equipment or facility, the amortization period could be reduced to 10 or even 5 years, increasing the annual capital charges.

The numbers in Tables 1.2c to 1.2f represent the operating costs per tonne of waste treated in 1994 Canadian dollars. The information presented in A.D. Little (1985, 1986) was corrected for 1994 by multiplying the 1985 costs by the ratio (i.e. 1.2045) of 1994-Index over 1985-Index (Machinery and Equipment Price Index). Details of the total costs are presented in individual sections for each technology (when available).

Other costs and prices

When available, other costs or prices for specific technologies will be included in the individual technical sections. The information may be from contacts from vendors with MOEE staff or from proceedings of conferences and papers.

1995 price for hazardous waste incineration

A recent survey conducted by Environmental Information Ltd (8) reviewed the 1995 prices asked by various incineration facilities in North America. The general trend has been a decline in the range of 15% since 1989 for solids and liquid organics and near 25% for aqueous streams. The prices were not reported by type of incineration technology used but by type of wastes. A summary of the findings has been translated in Canadian dollars per metric tonne, and reported in Table 1.2i.

References

1. U.S. EPA, 1990. International Waste Technologies/Geo-Con in situ stabilization/solidification. Applications analysis report. Superfund innovative technology evaluation (SITE). EPA/540/A5-89/004.

2. Freeman, H.M., 1989. Standard Handbook of Hazardous Waste Treatment and Disposal, McGraw-Hill, ISBN 0-07-022042-5.

3. Jack Donnan, 1995. Economic Services Branch, MOEE. Personal communication (May 8, 1995).

4. Statistics Canada, 1995. Construction Price Statistics, First Quarter 1995. Cat. No. 62-007.

5. Edgar Schmidt, 1995. Ontario Waste Management Corporation (OWMC). Personal communication (July, 1995).

6. A.D. Little, 1986. Technologies and systems for treatment and disposal of special wastes in Ontario. Final report to Ontario Waste Management Corporation, by Arthur D. Little of Canada Limited, October 2, 1986.

7. A.D. Little, 1985. Systems and technologies for treatment and disposal of special wastes in Ontario. Draft report to Ontario Waste Management Corporation, by Arthur D. Little of Canada Limited, February 8, 1985 (unpublished).

8. EI Digest, 1995. Hazardous waste incineration 1995. EI Digest, May 1995, p.31-38.

Table 1.2a: Cost categories (1)

COST CATEGORY	COMMENTS
1. Site preparation	• Site specific • Assuming typical/minimal site preparation
2. Permitting & Regulatory	• Based on general MOEE Approval fee (2% control equipment cost)
3. Capital equipment	• Represent about 50% of total cost (10 year amortization) • Based on Canadian Dollars (1994) • Corrected for US $ and prior to 1994 by Price Index
4. Startup	
5. Labour	• Based on typical trades fees (Can.$)
6. Consumable & Supplies	• Part of operating costs.
7. Utilities	• Part of operating costs.
8. Effluent treatment & disposal	• Broad estimates, specially if extensive effluent treatment required
9. Waste shipping & handling	• Generally not considered in this report.
10. Analytical services	• For QA/QC (not part of operating costs)
11. Repair, replacement, Modification	• Part of operating costs.
12. Demobilization	• Not included, since assuming permanent operation (over 20 years)
TOTAL	• Estimated range (order of magnitude)

TABLE 1.2b: Price Index (4)

	Machinery and Equipment Price Index (1986 = 100)	
YEAR	Petroleum and Coal Products Sector	Chemicals and Chemical Products Sector
1985	97.7	97.3
1986	100.0	100.0
1987	99.7	99.7
1988	99.5	99.5
1989	104.1	104.1
1990	105.9	105.9
1991	103.9	103.3
1992	108.0	107.2
1993	113.4	112.0
1994	118.8	117.2

Table 1.2c: Operating costs for physical treatment (6,7).

Physical Processes	**Operating costs (1994 $/tonne)**
Adsorption	80
Air Flotation	40
Air Stripping	5
Autoclaving	--
Centrifugation	2
Chelation	--
Distillation	--
Electrodialysis	2
Emulsion Breaking	10
Evaporation	25
Filtration	2
Freeze Crystallization	8 - 53
Heavy Media Separation	--
Ion Exchange	5
Irradiation	--
Liquid/Liquid Extraction	--
Oil/Water Separation	--
Reverse Osmosis/Ultrafiltration	2
Screening	--
Sedimentation	2
Solvent Extraction	90
Steam Stripping	12

Table 1.2d: Operating costs for chemical treatment (6,7).

Chemical Processes	**Operating costs (1994 $/tonne)**
Alkali Metal Dechlorination	--
Alkaline Chlorination	--
Catalytic Dehydrochlorination	--
Chemical Oxidation	42
Chemical Precipitation	7
Chemical Reduction	40
Hydrolysis	--
Electrolytic Oxidation	--
Neutralization	10

Table 1.2e: Operating costs for biological treatment (6,7).

Biological Processes	**Operating costs (1994 $/tonne)**
Activated Sludge	20
Anaerobic Digestion	20
Biological Adsorption	20
Fixed Bed Reactor	--
Fluidized Bed Reactor	20
Land Treatment	35
Waste Stabilization Lagoon	45
Wet Lands	--

Table 1.2f: Operating costs for Solidification Stabilization processes (6,7)

Solidification / Stabilization Processes	Operating costs (1994 $/tonne)
Pozzolanic Processes	40
Encapsulation	40
Polymerization	40
Sorption	40
Vitrification	--

Table 1.2g: Operating costs for thermal processes (6,7)

Thermal processes	Operating costs (1994 $/tonne)
Fluidized Bed Incineration	125*
Liquid Injection Incineration	115*
Pyrolysis	102*
Rotary Kiln	150*

(*): excluding credits for energy recovery.

Table 1.2h: Operating costs for other processes (6,7)

Other processes	Operating costs (1994 $/tonne)
Engineered Landfill	90
Deep-well Injection	20
Isolation	210
Storage	130

Table 1.2i: 1995 prices for incineration ⁽⁸⁾

Waste types	1995 market prices (range: $/tonne)
Soils Non-pumpable wastes	185 - 275
Sludges Pumpable wastes	120 - 335
Drums (soils/sludges)	245 - 430
Organics (fuel blendable)	90 - 155
Aqueous wastes	95 - 100

1.3 TECHNOLOGY SELECTION

The selection of a technology for treatment of hazardous waste can be based on two main factors: nature of the waste and economics.

The nature of the waste, quantity, availability over a number of years will justify the need to establish a treatment system and facilities (1). It is essentially driven by a market analysis and a business decision.

Pretreatment of the incoming wastes to the treatment facility can be of benefit in the selection of a suitable technology. Evaluation of the waste generating process at the generator site can even prevent costly pretreatment and final treatment of the waste. This evaluation may even include pollution prevention and cost saving to the generator (recovering of valuable materials and reduction of waste volume). Knowing thoroughly the range of operation of the treatment process, and how it can be modified to extend its application, can also be beneficial. This is an innovative approach to develop new business and provide cost effective waste management. This approach is used in Ontario by some waste treatment facilities (1) .

Selection approach

A more systematic selection approach can be used in search of the best technologies available. A number of factors and ranking can be used. As an example, we summarize the selection protocol used in the selection of technologies for the OWMC proposal (2):

1) Protection of public health and safety under abnormal events.

2) Protection of public health and the environment under normal operations.

3) Input flexibility: treatment effectiveness for various waste types and waste composition.

4) Operational flexibility: ability to start and stop the treatment.

5) Operational reliability: reliability of process equipment, minimizing downtime.

6) Technical reliability: ease of operation and monitoring.

7) Relative capital and operating costs.

Various results on the evaluation are presented in the report of A.D. Little (2).

Reference

1. Laidlaw, 1995. Personal communication: meeting of STB/MOEE staff with Eric Hunter (Director, Special Projects) and Blake Nesbitt (Technical Manager), Laidlaw Environmental Services Ltd., June 14, 1995.

2) A.D. Little, 1986. Technologies and systems for treatment and disposal of special wastes in Ontario. Final report to Ontario Waste Management Corporation, by Arthur D. Little of Canada Limited, October 2, 1986.

2. PHYSICAL TREATMENT PROCESSES

2.1 ADSORPTION

Process summary

Some solids, such as activated carbon or resins, readily attach dissolved chemicals to their surface. When these solids are removed from the mixture, the attached material is also removed. Because the adsorption process is reversible, the adsorbent can generally be reused after the chemicals are desorbed from the adsorbent by using heat or chemical re-generating treatments.

Adsorption principles

A number of attractive forces are responsible for the adsorption of the contaminant molecules (either as a gas or a liquid) onto the adsorbent. These forces exist because of the electromagnetic interactions of nuclei and electrons of the contaminants and the adsorbent. Physical adsorption results from weak interactions produced by the motion of electrons within the molecules. Chemical adsorption (or chemisorption) involves electronic interactions between the surface of the adsorbent and the molecules in solution. The bonds from chemical adsorption are much stronger than the ones from physical adsorption. Electrostatic adsorption is the third and strongest force in the adsorption process and is caused by ionic charges between the contaminant and the adsorbent.

The adsorption kinetics involve three consecutive steps. First the contaminant molecule (adsorbate) moves from the contaminated fluid to the exterior surface of the absorbent. Terms such as "surface film" or "hydrodynamic boundary layer" refer to the fluid immediately surrounding the adsorbent particles. Second, the adsorbate moves from the exterior of the adsorbent particle through the pores for adsorption. Thirdly, the molecule is actually adsorbed in the pores and held to the surface.

In liquid solutions, the adsorption capacity of the adsorbent generally increases with the decrease of the solubility of the contaminant (which is related to the increase of its molecular weight). Experimentally, the properties of the adsorbent are expressed graphically as "isotherms": concentrations of the contaminant in the adsorbent are plotted as a function of the contaminant concentrations in the solution. Depending on the type of adsorbent and adsorbate, the relationship may be linear (linear isotherm), may reach a plateau (Langmuir isotherm) or may be concave or convex (Freundlich isotherms).

Treatment processes

The manner in which the adsorbate is exposed to the adsorbent is an important design consideration, depending on the controlling factors of the adsorption process (controlled by film transport or by pore diffusion). The most common reactor designs are:

1. completely mixed batch (CMB);
2. completely mixed flow (CMF);
3. columns in series
4. columns in parallel;
5. pulsed or moving bed.

The designs are illustrated in Figure 2.1a.

In the CMB reactor, the adsorbent is added to the contaminant solution in the reactor tank and constant mixing is maintained. The advantage of this process is the control of the quality of the effluent. The obvious disadvantage is that the process is essentially a batch and manual process. Also, the CMB system does not utilize efficiently the adsorption capacity of the adsorbent, since the process is driven gradually to an equilibrium stage.

In the CFB reactor, the contaminant solution and the adsorbent are continually added to the tank and the mixed solution is withdrawn at the same rate. The quality of the effluent is usually function of the quality of the influent, since the system operates under a steady-state solution concentration. The disadvantage lies also in the inefficiency in the use of the adsorption capacity, since more adsorbent is used than necessary to maintain the process.

For both types of reactor (CMB or CFB), a clarifier or settling tank are usually used to separate the used adsorbent and the treated solution. In the CMB process, it is possible to use the reactor tank as the settling tank.

In the column reactor design, the contaminated solution enter a column of adsorbent either from the top (downflow) or from the bottom (upflow) of the column. An adsorption zone (also called mass-transfer zone) quickly develops in the column, where the contaminant concentration in the adsorbent changes from the influent value (saturation of the column) to virtually zero concentration. This adsorption zone gradually move downward in time as more influent is treated from the top. At the time of breakpoint (saturation of the column at the bottom), the column must be replaced. The major advantage of this system is the very efficient use of the adsorption capacity, due to equilibrium conditions in the saturated section of the column. The reaction rate is also higher since any section of the column is exposed to increasing concentration of the contaminants.

Applicability and efficiency

- More suitable for organic contaminants that are nonpolar, with low solubility, and of high molecular weight (e.g. biphenyls, phenols, perchloroethylene).
- Less efficient for inorganic compounds, because of problems in the regeneration process.

Advantages

- Adsorbent can be re-generated and re-used a number of times.
- Process can be used for a wide range of organic contaminants, in gaseous or liquid forms.

Limitations

- Development of excessive head loss due to suspended-solids accumulation or biological growth in the bed -- remediated by frequent backwashing and reversing the flow.
- Development of hydrogen sulphide (highly corrosive) due to biological growth in the bed.
- Premature exhaustion of the adsorption capacity, due either to inadequate re-generation or contaminants.

Cost evaluation

The capital cost for a treatment capacity of 1,500 tonnes/year is estimated at $92,000, based on a detailed study (2) done in 1985 and indexed to 1994 Canadian dollars. The operating costs, including materials ($86,500), electricity ($1,900), labour ($21,000), maintenance ($4,600) and other ($4,600), can be translated to approximately $80/tonne of waste treated (aqueous solution).

Approval requirements

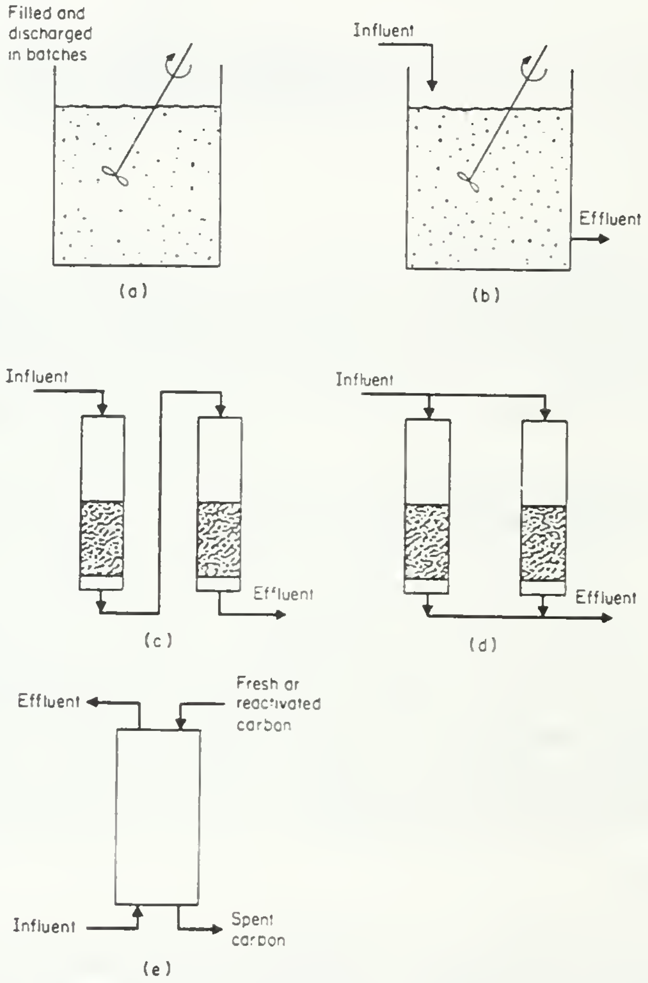
Carbon adsorption will generally generate 100 kg/tonne of spent carbon, based on aqueous steams less than 10% organics. The carbon maybe suitable for regeneration or disposal as a solid waste or incineration (2).

References

1. Freeman, H.M., 1989. Standard Handbook of Hazardous Waste Treatment and Disposal, McGraw-Hill, ISBN 0-07-022042-5.

2. A.D. Little, 1985. Systems and technologies for treatment and disposal of special wastes in Ontario. Draft report to Ontario Waste Management Corporation, by Arthur D. Little of Canada Limited, February 8, 1985 (unpublished).

Figure 2.1a: Reactor configuration for adsorption systems.



(Source: Freeman, 1989)

LEGEND:
(a) completely mixed batch (CMB)
(b) completely mixed flow (CMF)
(c) columns in series
(d) columns in parallel
(e) pulse or moving bed.

2.2 AIR FLOTATION

Process summary

Air is injected into aqueous wastes where air bubbles adhere to the particles and cause the bubble/particle complex to float to the surface.

Process description

Air flotation, also referred to as Dissolved Air Flotation (DAF), is a process where air is injected under pressure into aqueous waste. The mixture of materials in a liquid is separated by adding micro air bubbles to the materials. The resulting increase of the density difference between the materials causes their separation as the material with the bubbles floats to the surface (1). The floats are removed from the surface and constitute DAF sludges.

Applicability and efficiency

- Widely used in the petroleum industry for separation of oily wastewater; DAF sludges are classified listed hazardous wastes in the petroleum industry.
- Applicable for wastes with densities close to that of water (e.g. light oils and solvents).
- Efficiency is function of the ability of the material to attract and hold on to micro-bubbles.

Advantages

- Relatively low operation cost.

Limitations

- Air emission controls may be required if hazardous volatile organics are present in the waste.

Cost evaluation

For a treatment capacity of 10,000 tonnes/yr, the operating costs are estimated at $40/tonne (1994 dollars) (1).

References

1. A.D. Little, 1986. Technologies and systems for treatment and disposal of special wastes in Ontario. Final report to Ontario Waste Management Corporation, by Arthur D. Little of Canada Limited, October 2, 1986.

2.3 AIR STRIPPING

Process summary

Air stripping involves passing air through a liquid or a solid with the result that volatile materials evaporate into the air flow. The air stream normally requires treatment to remove the contaminants.

Process principle

Under conditions of a dilute compound in solution, there exist a gas-liquid equilibrium relationship which can be expressed as Henry's law: the partial pressure of a gas or volatile compound A in the air is directly proportional to its concentration in the solution:

$$P_A = (H_A)(\phi_{A)}$$

where P_A = partial pressure of compound A in air.
H_A = Henry's law constant for compound A.
ϕ_A = mole fraction of A in water.

By dividing both side of the equation by P_T (total system pressure), we can determine the mole fraction of compound A in the air (Y_A):

$$Y_A = (H_A/P_T)\ \phi_A$$

The last equation indicates that under atmospheric pressure ($P_T = 1$ atm), the fraction of the volatile compound A in the air (at equilibrium state) is proportional to Henry's constant and the concentration of the contaminant A in the waste. The higher the Henry's constant, the better for air stripping (e.g. Henry's constant for vinyl chloride is 3.55×10^5 atmosphere, compared to 0.12 atm for pentachlorophenol).

Treatment process

Transfer of volatile contaminants from water to air can be achieved in aerated tanks, spray towers, and packed towers. The most efficient design is a packed tower with countercurrent flows of air and water (see Figure 2.3a).

The contaminated water enters the packed tower at the top and is distributed uniformly across the surface of the packing with the use of a liquid distributor. The wastewater flows downward along the packing surfaces. Channelling in the downward movement of water is prevented by redistributors along the tower length. The air is blown from the base of the tower and flows upward, contacting the water. Because of the tower design and the packing medium, the tower provides a high level of turbulence and a very large surface area for mass transfer. Volatile organics are transferred from the water to the air and carried out at the top of the tower.

Applicability and efficiency

- Remove only relatively volatile organic contaminants (e.g. toluene, trichloroethylene).
- Packed-tower air scooper can achieve >99% removal of volatile organics from water.
- Widest application in the remediation of aquifers contaminated with volatile solvents.

Advantages

- High removal efficiency at low contaminant concentrations.

Limitations

- Practical feed concentrations limited to about 100 mg/L organics.
- Pre-treatment required to remove suspended solids in the waste stream and dissolved ferrous iron (by oxidation) in groundwater.
- Transfer of a water-pollution problem to an air-pollution problem.
- Limited range for volatile contaminants.

Cost evaluation

The capital cost for a treatment capacity of 1,500 tonnes/year is estimated at $42,000, based on a detailed study (2) done in 1985 and indexed to 1994 Canadian dollars. The operating costs, including electricity ($720), labour ($10,500), maintenance ($2,100) and other ($2,100), can be translated to approximately $10/tonne of waste treated (aqueous solution).

Approval requirements

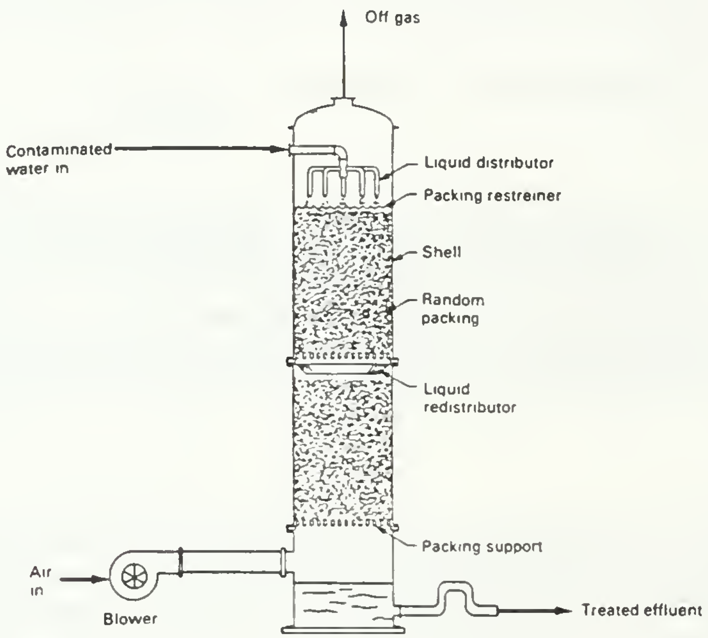
Air stripping essentially converts a water pollution problem to an air pollution problem. Depending on the concentration of the contaminants in the wastewater, the volume rate of air circulation, air emission may be acceptable under certain legislation. The air stream effluent must be treated in some cases, using either vapour-phase carbon adsorption technology or gas incineration technology.

References

1. Freeman, H.M., 1989. Standard Handbook of Hazardous Waste Treatment and Disposal, McGraw-Hill, ISBN 0-07-022042-5.

2. A.D. Little, 1985. Systems and technologies for treatment and disposal of special wastes in Ontario. Draft report to Ontario Waste Management Corporation, by Arthur D. Little of Canada Limited, February 8, 1985 (unpublished).

Figure 2.3a: Typical packed-tower air stripper



Source: Freeman, 1989.

2.4 AUTOCLAVING

Process summary

In autoclaving, a waste is heated with saturated steam in a pressurized container so that the microorganisms in the waste are killed. This process is applied specially for treatment of biomedical wastes.

Autoclaving principles

The process is based on the fact that most living microorganisms are destroyed when exposed to temperature above the boiling point of water, due to various fluids making up the living cells. Temperature above 100 °C are reached in the autoclaving chamber by keeping the steam under pressure.

Treatment process

The waste is loaded in batch into a vessel. Saturated steam is introduced in the vessel and kept typically in the pressurized vessel at 135 °C for up to 60 minutes. After treatment, the waste is hydraulically conveyed to a shredder, and then compacted for disposal.

Important manufacturers and vendors of autoclaving equipments are Amsco (Amsco Scientific, Division of American Sterilizer Company, Apex, North Carolina, USA), Sanipak (San-i-Pak™ Pacific Inc., Tracy, California, USA) and Consolidated (1).

Applicability and efficiency

- Applicable to biomedical (pathological) wastes.
- Can sterilize some biomedical wastes.

Advantages

- Low capital and operating costs.
- Sterilized and shredded plastics and metals potentially recyclable.

Limitations

- Efficiency and quality control of the process are critical for destruction of pathogens.
- Not applicable for all biomedical wastes (e.g. body parts, bulk liquids, volatile organics, radioactive material, chemotherapeutic drugs).

References

1. MOEE, 1995. Autoclaves for the decontamination of biomedical waste. Final report for project RAC 679G, prepared by Department of Microbiology & Immunology, Faculty of Medicine, University of Ottawa. April 1995.

2.5 CENTRIFUGATION

Process summary

Materials of different density are separated in a fluid by rapidly rotating the fluid mixture.

Centrifugation principle

The rotational force in centrifugation is analogous to the gravitational force in the sedimentation process. The centrifugal force can be equal however to several thousand times the force of gravity in sedimentation, depending on the rate of rotation. Within the centrifuge, heavier materials are deposited furthest from the centre of rotation, and lighter materials being closer to the centre. The separation process can be accelerated under high centrifugal forces.

Process description

There are two basic designs of centrifuges: sedimentation centrifuges and filtering centrifuges. In the sedimentation centrifuge design, the solids accumulate in a layer or cake (similar to sedimentation) on the inner wall of the rotating vessel. In the filtering design, a cake of solids is formed on a filter medium held in a rotating basket. This design is similar to a filter press, where the hydraulic force on the waste is replaced by the centrifugal force (3).

More specifically, the following designs are used (1):

- hydrocyclones (see Figure 2.5a)
- fixed-wall
- rotating- wall
- sedimenting centrifuges.

Applicability and efficiency

- Applicable to dewatering sludges, separating oils from water and clarification of viscous gums and resins.
- Efficiency depends on density difference of materials in mixture.

Advantages

- Better suited than vacuum filtration for dewatering sticky/gelatinous sludges.

Limitations

- Fails to remove less dense solids and small particles.
- Maximum concentration of solids in the centrifuged sludge is limited to about 15% .

Cost evaluation

The capital cost for a treatment capacity of 50,000 tonnes/year is estimated at $267,000 based on a detailed study (2) done in 1985 and indexed to 1994 Canadian dollars. The operating costs, including materials ($34,500), electricity ($4,900), labour ($42,200), maintenance ($13,400) and other ($13,400), can be translated to approximately $2/tonne of waste treated (various liquids and sludges).

Approval requirements

Centrifugation will generate typically 160 kg/tonne of cake for disposal or solidification.

References

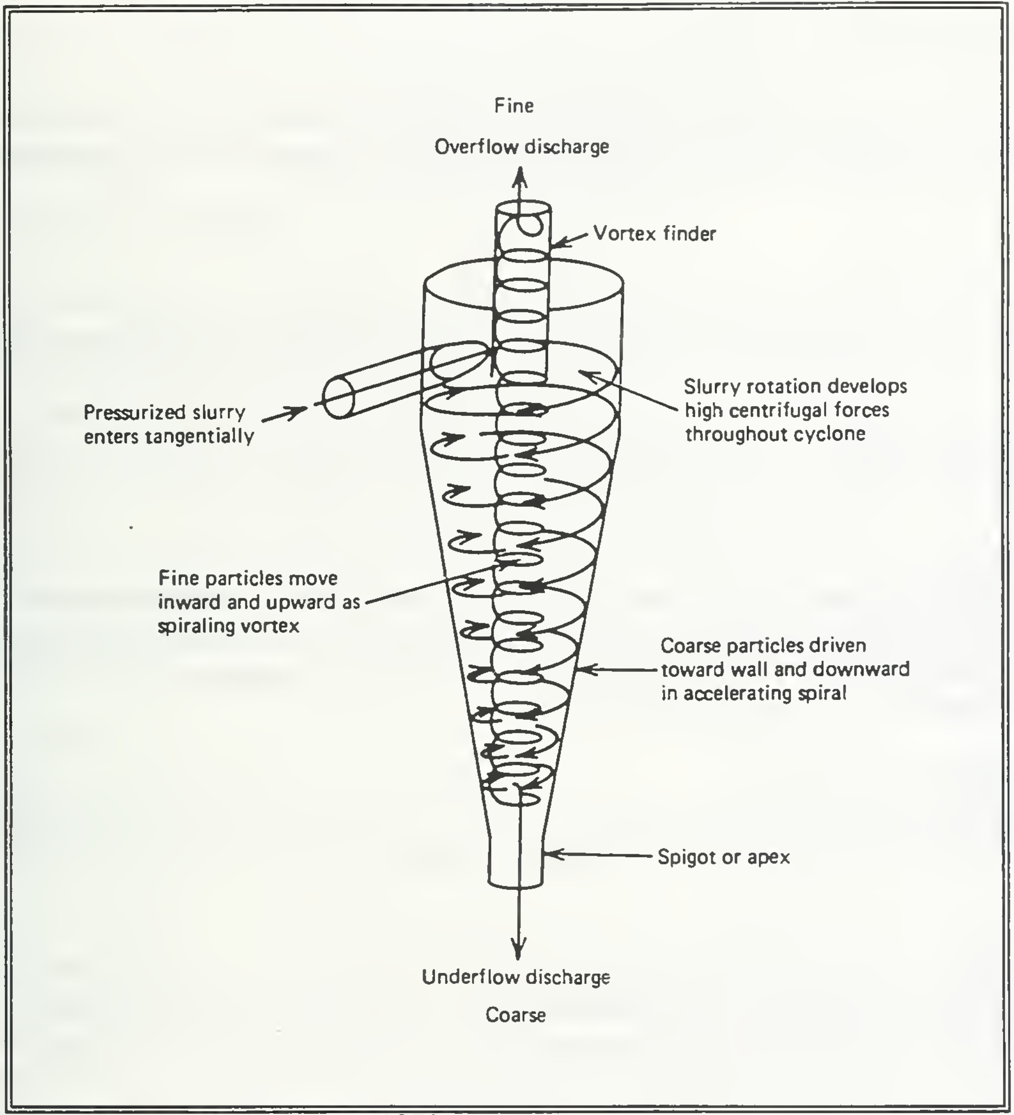
1. Freeman, H.M., 1989. Standard Handbook of Hazardous Waste Treatment and Disposal, McGraw-Hill, ISBN 0-07-022042-5.

2. A.D. Little, 1985. Systems and technologies for treatment and disposal of special wastes in Ontario. Draft report to Ontario Waste Management Corporation, by Arthur D. Little of Canada Limited, February 8, 1985 (unpublished).

3. Proctor & Redfern, 1982. Generic process technologies study. Revised report (December 1982) for OWMC Environmental Assessment, Volume C2.

4. Kirk-Othmer, 1979. Encyclopedia of chemical technology. Third Edition. Ed. John Wiley & Sons, Toronto. Volume 5, pp. 857-862.

Figure 2.5a: hydrocyclone design


Fine
Overflow discharge
Vortex finder
Slurry rotation develops high centrifugal forces throughout cyclone
Pressurized slurry enters tangentially
Fine particles move inward and upward as spiraling vortex
Coarse particles driven toward wall and downward in accelerating spiral
Spigot or apex
Underflow discharge
Coarse

Source: Kirk-Othmer, 1979.

2.6 CHELATION

Process summary

A chemical agent combines with a contaminant metal in solution, so that the metal is separated from other materials. The resulting chelated metal can then be removed from the mixture.

Chelation principle

Certain organic compounds and resins have unusually high selectivity for specific metal ions. The chelating agent will donate one atom to replace it with a specific metal atom. Because of the complex molecular connections between atoms and the metal (called chelation complex or chelate), the chelate ring gives the appearance of a metal atom being held in a pincer (like the chela of a lobster).

Chelation happens naturally in the environment. For examples, a number of delicate balanced life processes depend on traces of metal ions in cells and fluids, such as blood oxygenation and muscle contraction. Chelation is used in industrial applications such as scale removal form steam boilers, water softening, food preservation, chemical analysis and crop fertilization (1).

Applicability and efficiency

- Chelating chemicals are commercially available.

Advantages

- Chelating chemicals can be selected for their affinity to particular metals.
- Chemicals can be recovered and reused.

Limitations

- Interference of fats and oils with the process.
- Excess chelating chemicals can contaminate treated liquids.

References

1. Kirk-Othmer, 1979. Encyclopedia of chemical technology. Third Edition, Volume 5. Ed. John Wiley & Sons, Toronto. p.339-368.

2.7 DISTILLATION

Process summary

Distillation involves the separation of more volatile materials from less volatile materials by using a process of vaporization followed by a process of condensation.

Distillation principles

Distillation involves application of sufficient heat to raise the temperature of the mixture to a predetermined level to vaporize part of the mixture. Heat is removed from the vapour mixture to condense it into a distillate.

Simple continuous distillation (also called flash distillation) involves a constant feed of the mixture to the distillation equipment. The liquid and vapour mixture is in equilibrium, and this generates a crude separation of the materials.

Multiple staging is used to increase the separation efficiency. Multiple staging is obtained by returning part of the distillate to the top of the still, thereby bringing this reflux liquid into intimate contact with the rising vapours.

Treatment processes

Distillation can be conducted in either batch mode or continuous mode. Most large-scale industrial distillations utilize however continuous mode.

In the batch mode, the equipment consists of a heated vessel (still), a condenser to condense the vapour, and an accumulator (if multiple staging, or reflux, is used). The operation involves boiling a batch of the feed mixture and condensing and collecting the distillate. To obtain products within a narrower boiling point range, a rectification column is used with the reflux (see Figure 2.7a). The operation involves a batch of feed brought to steady state under total reflux conditions. Once steady state is reached, removal of some of the overhead product is done. The quality of the overhead product is controlled by proper adjustment of the reflux ratio. Bach distillation mode is preferred when the composition of the feed varies significantly or when the feed contains significant amounts of solids that would tend to foul and plug a continuous unit.

In the continuous mode, the feed is continually introduced to the system at the same time as distillates and residues are constantly removed from the overhead and bottom parts of the distillation column. As illustrated in Figure 2.7b, the feed can be pre-heated in a heat exchanger (point G in the figure) and introduced to the mid section of the distillation column (A). The column is designed to provide intimate contact between vapour and liquid, and packed with various engineered beads and rings, separated by trays, plates and valves. The cascade (set of plates) above the feed point is called rectifying section (or enriching section) and the cascade below the feed point is called stripping section. The feed introduced in the stripping section is stripped of the more volatile components by the rising vapour in that section, while the vapour rising through the rectifying section is washed with the liquid reflux to remove the less volatile components. The overhead vapour is condensed by a condenser (C) and collected in the accumulator (D). A portion of the distillate is continuously withdrawn as the overhead product from the cooler (E), while the remainder is recirculated to the column as reflux. The liquid at the bottom of the column is reboiled (B) again to capture residual volatile compounds which are recirculated to the stripping section. The bottom residues of the reboiler are cooled (G) and disposed as bottom products.

Applicability and efficiency

- Widely applicable to volatile and semivolatile organic contaminants in a liquid form.
- Limited to free-flowing fluid with negligible solids content.
- Most suitable for liquid organics (solvents and halogenated organics) such as: plating wastes containing organic component, aqueous wastes containing phenol, ethylbenzene-styrene mixtures; waste solvents, waste lubricating oils.

Advantages

- Extraction of specific fractions of the waste stream for potential recycling (e.g. waste solvent recycling).

Limitations

- Complex operation, requiring comparatively large equipment.
- Expensive equipment requiring high capital-recovery charges.
- Complex distillation equipment requiring highly skilled personnel.
- High energy requirement (compared to air stripping or steam stripping).
- Requires pre-treatment and filtration of suspended particulates.

Cost evaluation

The capital cost of a distillation system is dependant on a number of design variables which take into account the type of feed stream and the distillation components and the purity required of the distillate and/or the quality of the bottom residues. These design variables include:

- size and type of reboiler
- height, diameter and internals of distillation column
- degree of automation
- material of construction (corrosion, etc.).

The installation cost can be between 25% to 50% of the equipment cost(1). However, other estimates go as high as 150% to 200% of the equipment cost (2). Pre-assembled process systems or process modules are also available from most system suppliers, and savings of 25% to 40% on the installation cost is possible.

The operating costs is function of the size of the operation, ranging from a small batch distillation system to a large continuous process system. On a unit-cost basis, the steam usage is equivalent for a small or a large system. For other operating costs such as labour and maintenance, the unit-costs become less important for large systems.

Approval requirements

Solids residues will form in coolers and condensers and in traps at various points in the distillation circuit.

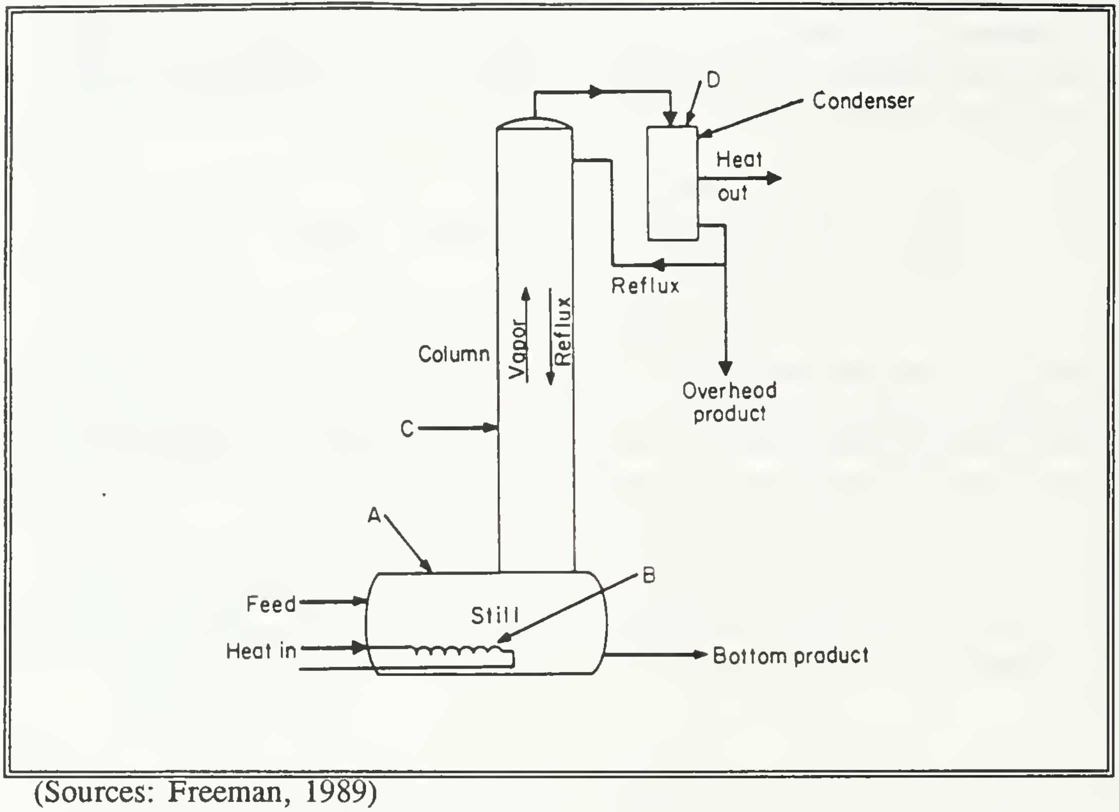
Air emissions are not expected, except during process upsets or incidents. Air emissions should be monitored however, depending on the efficiency of the condensers and the volatility of the organics present in the waste.

References

1. Freeman, H.M., 1989. Standard Handbook of Hazardous Waste Treatment and Disposal, McGraw-Hill, ISBN 0-07-022042-5. p. 6.23-6.38.

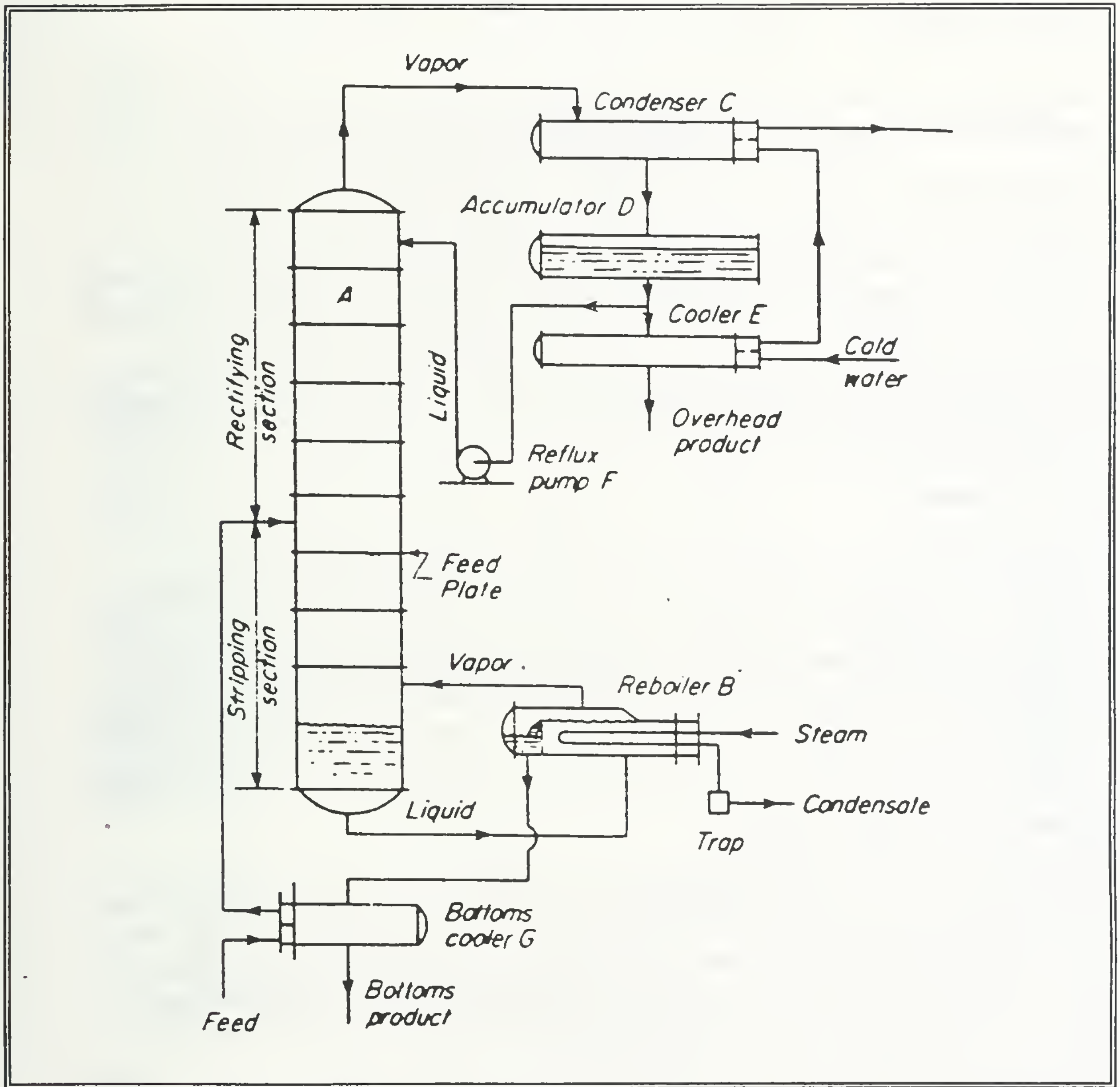
2. Distillation Handbook, 2nd Ed., DH-682, APV Equipment Inc., 395 Fillmore Ave., Tonawanda, New York, 1982.

Figure 2.7a: Batch distillation process



(Sources: Freeman, 1989)

Figure 2.7b: Continuous distillation process



(Source: Freeman, 1989)

2.8 ELECTRODIALYSIS

Process Summary

Electrodialysis relies on ion-exchange membranes and direct-current electrical field to separate ionic contaminants in a solution.

Electrodialysis principle

The process requires electrodes on both sides of a membrane and involves electrically charging the electrodes in a solution bath. The membranes are designed to allow only negative or positive ions to pass through. When the ions are attracted to the oppositely charged electrode only one type of ion can pass through the membrane. This results in a cleaned liquid (permeate) and a liquid with concentrated contaminants (concentrate).

Process design

An electrodialysis cell consists of an anode and a cathode, separated by cation-selective membranes, liquid flow chambers and anion-selective membranes (see Fig. 2.8a). The waste feed is introduced in the system between the anionic and cationic membranes. The cationic membrane allows only cations to pass through, and the anionic membrane only anions. Under direct voltage on the cell, cations (positively charged ions) are attracted to the cathode (negatively charged), and anions (negatively charged ions) are attracted to the cathode (positively charged). The effect is that ions in the waste feed passe through the appropriate membranes and reduce the contaminants in the feed stream.

The development of the electrodialysis reversal process has reduced significantly the complications due to fouling of the membranes by suspended solids and salts. By using membranes that can operate in either anionic or cationic modes and electrodes (platinum-coated titanium) that can operate as either cathodes or anodes, the ionic flow is reversed. For a 20 minute cycle system, a proper reverse flow may last 1-2 minutes for adequate purging of the membrane.

Applicability

- Applicable only to ionic contaminants.
- Greatest potential users: metal finishing and electroplating industry in the regeneration of plating baths and recovery of precious metals.
- Produce moderate-quality product water (several 100 mg/L salt) and concentrated streams up to 20% salt.

Advantages

- Concentrate steams suitable for ions/metals recycling.

Limitations

- Capital cost and energy consumption increase with raise of concentration in total dissolved solids (TDS).
- Technology is generally limited to feed streams with moderate TDS contents.
- Normal fouling of the membranes requires cyclic reversal flow electrodialysis to clean the membranes.

Cost evaluation

The capital cost for a treatment capacity of 19,500 tonnes/year is estimated at $78,000 based on a detailed study (3) done in 1985 and indexed to 1994 Canadian dollars. The operating costs, including materials ($3,600), electricity ($1,800), labour ($21,000), maintenance ($3,900) and other ($3,900), can be translated to approximately $2/tonne of waste treated (various aqueous solutions with metals).

Approval requirements

Electrodialysis will generate typically 150 kg/tonne of aqueous stream with 30,000 ppm dissolved solids and 850 kg/tonne aqueous stream with less than 500 ppm dissolved solids (3).

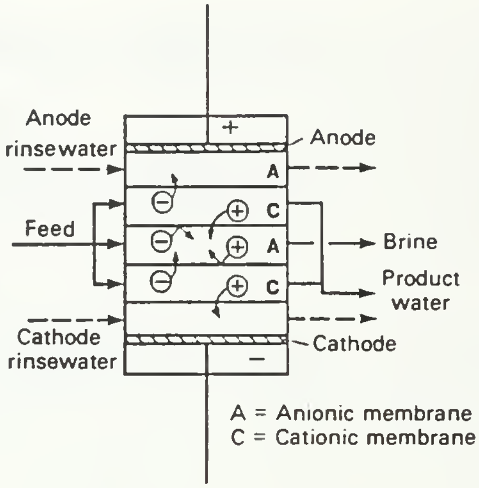
References

1. Freeman, H.M., 1989. Standard Handbook of Hazardous Waste Treatment and Disposal, McGraw-Hill, ISBN 0-07-022042-5.

2. McCoy and Associates Inc., 1985. "Membrane separation technology: applications to waste reduction and recycling", The Hazardous Waste Consultant, 3:(3) (May-June 1985), p.4-21.

3. A.D. Little, 1985. Systems and technologies for treatment and disposal of special wastes in Ontario. Draft report to Ontario Waste Management Corporation, by Arthur D. Little of Canada Limited, February 8, 1985 (unpublished).

Figure 2.8a: Diagram of electrodialysis cell



Source: The Hazardous Waste Consultant (1985).

2.9 EMULSION BREAKING

Process summary

Some liquid mixtures are so intimately mixed that the different materials will not separate into their individual parts. Mixing in another chemical allows the liquid mixture components to separate and to either float or sink apart.

Process description

Emulsion breaking is usually accomplished by acidifying the aqueous solution to cause the oil and water phases to separate. Settling takes place in a tank where floating oil is skimmed from the surface. Two waste streams are generated from the process: oily residues and acidic water.

Applicability and efficiency

- Applicable to oil/water mixtures.
- Operated as batch process.

Advantages

- Relatively simple process, requiring only proper mixing.

Limitations

- Introduction of emulsifier in the waste stream, which needs to be treated or disposed of.
- Periodic monitoring (visual inspection) is required to ensure emulsion separation.

Cost evaluation

The capital cost for a treatment capacity of 8.000 tonnes/year is estimated at $133,000 based on a detailed study (2) done in 1985 and indexed to 1994 Canadian dollars. The operating costs, including materials ($41,000), electricity ($2,600), labour ($20,500), maintenance ($6,600) and other ($6,600), can be translated to approximately $10/tonne of waste treated (various oily wastes).

Approval requirements

Emulsion breaking will generate typically 250 kg/tonne of acidic oily solids and 800 kg/tonne of acidic aqueous stream which require additional treatment (neutralization and separation) (2).

References

1. A.D. Little, 1986. Technologies and systems for treatment and disposal of special wastes in Ontario. Final report to Ontario Waste Management Corporation, by Arthur D. Little of Canada Limited, October 2, 1986.

2. A.D. Little, 1985. Systems and technologies for treatment and disposal of special wastes in Ontario. Draft report to Ontario Waste Management Corporation, by Arthur D. Little of Canada Limited, February 8, 1985 (unpublished).

2.10 EVAPORATION

Process Summary

Evaporation is the separation of two materials, typically a solid and a liquid, by heating the mixture so that one material evaporates out of the mixture.

Evaporation principle

Evaporation involves the conversion of a liquid into vapour. Evaporation differs from distillation in that no attempt is made to fraction the vapour back to various compounds. However the vapour is usually condensed and recovered for disposal.

The objective of evaporation is to concentrate a waste mixture by driving off the volatile solvent (mostly water) as a vapour from the rest of the mixture. The residue not evaporated is generally a more viscous liquid, unlike the solid residue produced by a drying process.

The amount of heat required to vaporize the volatile solvent is called the latent heat of vaporization. The energy (heat) required to run the process will depend on the latent heat of the solvent.

Evaporation processes

There are two processes generally used for evaporation: boiling heat transfer and flash vaporization.

Boiling heat transfer is the most commonly used process when evaporation is used. The liquid is heated to a vapour on the surface of an evaporator. The most common designs of evaporators are the rising-film evaporator and the falling-film evaporator.

Flash vaporization takes place in a pressure vessel (forced-circulation evaporator), where the vacuum pressure is maintained below the saturation vapour pressure of the liquid. This way, the sensible heat released during the cooling of the vapour is sufficient to evaporate the liquid entering the vessel.

Rising-film evaporator

In this design (see Fig. 2.10a), the liquid waste feed (F) enters the bottom of the heated tubes. As the liquid begins to boil, the vapour moves upward carrying liquid with it, resulting in an upward moving film (rising film) on the interior of the heated tubes (similar to the familiar percolator action in coffee makers). The vapour and the non-evaporated liquid are separated by the deflector plate. Further separation of the vapour and the liquid is done by the entrainment separator. The liquid product (P) is collected in an annular vessel and circulated to the next evaporator train. The vapour (V) is condensed in a heat exchanger, and the heat used in the next evaporator.

Falling-film evaporator

In the falling-film design (see Fig. 2.10b), the waste feed (F) is pumped to the top of the heating tubes or plates. As the feed flows downward, it is heated to boiling point. The vapour (V) is separated from the liquid through the sharp 180 degrees turn to the entrainment separator, and the liquid recirculated to the top of the tower or collected (P).

Forced-circulation evaporator

In this design (see Fig. 2.10c), the liquid is evaporated by flash vaporization. The waste feed (F) is continuously recirculated from the reservoir to the heating element. Sufficient pressure is maintained in the heater to present boiling of the liquid in the tubes. Flash vaporization occurs when the liquid re-enter the reservoir, which operates at a pressure slightly lower than the saturation vapour pressure of the liquid.

Other designs

Solar evaporation is the most effective evaporation technique for treatment of hazardous waste, because of the simplicity of the design, which requires large engineered surface ponds (with liners and berms). Although it conserves energy, requires low capital investment, can treat non-homogeneous waste streams, the process is greatly dependant on climatic conditions (humidity, precipitation, wind velocity and solar radiation): evaporation should exceed rainfall by a factor of 2 for optimum operation. It requires also large surface of land, and good liner integrity.

Applicability and efficiency

- Often used as a pre-treatment method to decrease quantities of material for final treatment.
- Waste stream must be characterized and relatively homogeneous in composition.

Advantages

- Process very selective, based on the specific boiling point of each material.

Limitations

- High capital and operating costs.
- High energy requirements.
- Potential operational problems: salt buildup on heat-exchange surfaces, foaming, and solid decomposition.

Cost evaluation

For an evaporation system designed at a capacity of 75,000 tonnes/yr, the operating cost of approximately $25/tonne can be expected (2).

Approval requirements

Evaporation will produce about 150 kg/tonne of brine concentrate of wet solids and near 850 kg/tonne of vapour containing volatile organics and traces of inorganics (3).

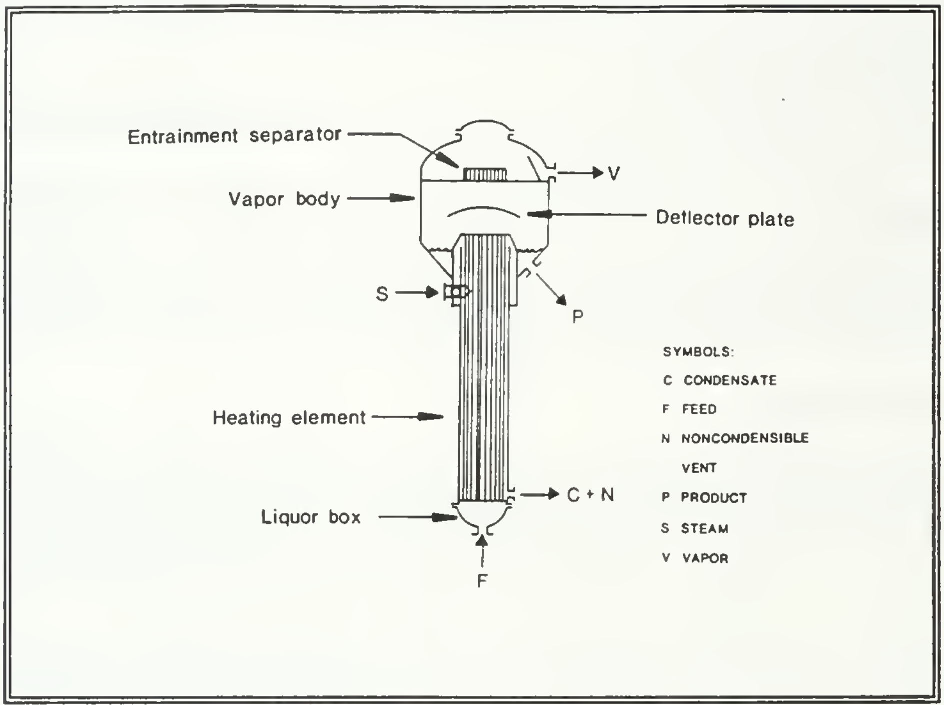
References

1. Freeman, H.M., 1989. Standard Handbook of Hazardous Waste Treatment and Disposal, McGraw-Hill, ISBN 0-07-022042-5.

2. A.D. Little, 1986. Technologies and systems for treatment and disposal of special wastes in Ontario. Final report to Ontario Waste Management Corporation, by Arthur D. Little of Canada Limited, October 2, 1986.

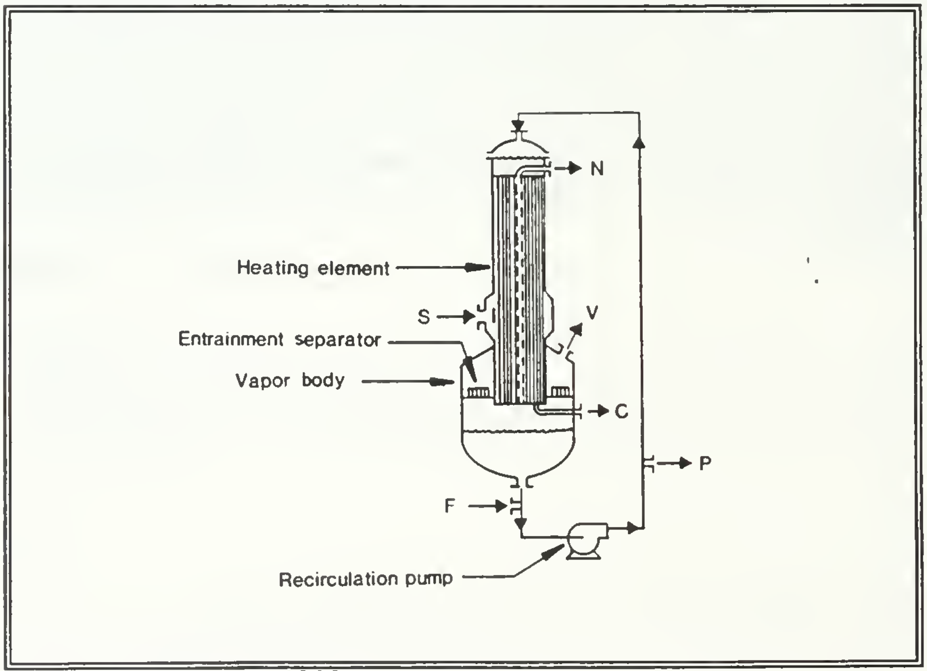
3. A.D. Little, 1985. Systems and technologies for treatment and disposal of special wastes in Ontario. Draft report to Ontario Waste Management Corporation, by Arthur D. Little of Canada Limited, February 8, 1985 (unpublished).

Figure 2.10a: Typical rising-film evaporator



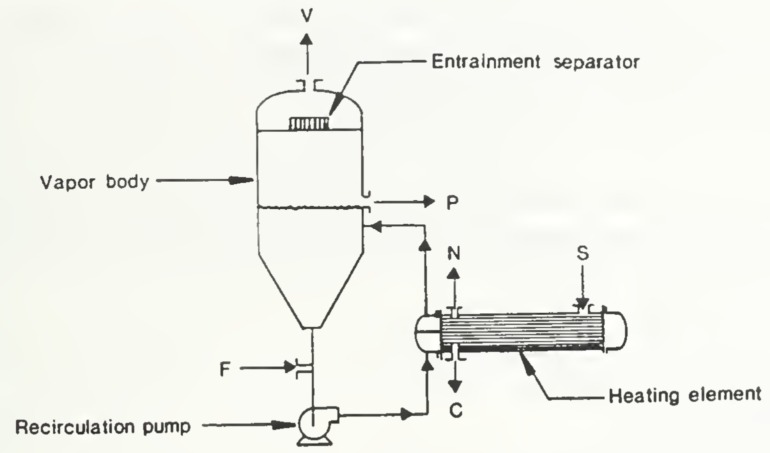
Source: Freeman, 1989.

Figure 2.10b: Typical falling-film evaporator



Source: Freeman, 1989.

Figure 2.10c: Design of forced-circulation evaporator



Source: Freeman, 1989.

2.11 FILTRATION

Process summary

Filtration involves the removal of a solid from a liquid by using a filtering medium to catch the solids while the liquid passes through the filter.

Process classification

Filtration is one of the methods used in the broader classification of separation technologies (1). Separation technologies include:

a) membrane separation
  - reverse osmosis (see section 2.18)
  - ultrafiltration (see section 2.18)
  - hyperfiltration
  - electrodialysis (see section 2.8)

b) gravity separation
  - air flotation (see section 2.2)
  - clarification
  - thickening
  - fixed-wall sedimentation
  - hydrocyclones (see section 2.5)
  - rotating-wall sedimentation
  - centrifugation (see section 2.5).

c) filtration
  - deep-bed filtration: granular bed, cartridge (see section 2.11.1)
  - cake filtration: vacuum filters, filter presses, belt filters, centrifugal filters (see section 2.11.2)
  - screening: screens (see section 2.19), crossflow filters (see section 2.11.3).

2.11.1 DEEP-BED FILTRATION

Process principles

The liquid waste (containing typically less than 100 ppm of suspended solid) is forced through a porous medium, where physical and chemical forces cause the solids to be captured and retained by the medium. The process is usually a batch process, where the filtering medium has to be replaced or cleaned when the pressure-drop across the medium is too high or when the level of suspended solids passing through the filter is unacceptable.

Process design

For industrial wastewater, granular-bed filters are usually used. The filters consist of a tank and an underdrain covered by a grid which supports a bed of granular materials. The granular materials may be of one type (uniform bed) or may be composed of stratified layers of different materials (multiple bed). The wastewater is fed uniformly on the top of the bed by a manifold.

At the end of the filtration run, the bed is usually cleaned by dislodging the trapped particles by agitating the bed with air and by backwashing with water.

2.11.2 CAKE FILTRATION

Process principles

The solid particles are retained at the surface of a porous medium as the liquid waste flows through the medium. The solids accumulate as a cake on the medium surface. In effect the cake becomes part of the filter medium itself, as the thickness of the cake increases. At the end of cycle, the cake is dewatered further (by mechanical compression or by air drying) and removed from the medium. The medium is washed and re-used.

Process design

There are various designs for cake filtration:
- rotary vacuum belt filters
- rotary vacuum precoat filters
- filter press
- belt filter press

Rotary vacuum belt filters

Rotary vacuum belt filtration is the most widely used method for sludge dewatering. The filter medium is a continuous belt of fabric going around a horizontal rotating drum and several rollers (see Fig. 2.11a). The drum is partially immersed in a shallow tank containing the feed slurry or waste. The drum is perforated and divided in sections which support the filter belt. A multi-port valve connects each section to either a vacuum system or a filtrate pump. As each section is alternatively immersed into the feed slurry, the filtrate pump extracts the filtrate through the filter where a cake gradually forms. The section emerges from the tank and the cake is dewatered by the vacuum system. As the belt is pulled away from the drum and over the rollers, the cake breaks away from the belt. The belt is spray-washed before being re-immersed into the slurry tank.

Applicability and Efficiency

- Effective in dewatering sludges which form thick and dry cake to be discharge by the rollers;

Advantages

- Continuous process requiring relatively little operator attention;

Limitations

- Thin, gelatinous sludges cannot be dewatered;
- Power consumption by vacuum system is relatively high.

Rotary vacuum precoat filters

In this variation of the rotary vacuum filter design, the filter medium covers the entire drum face, replacing the filter belt. Before the actual filtration cycle, the drum is precoated with a layer (up to 15 cm) of filter material (such as diatomaceous earth). The pre-coating process uses a slurry of filter material replacing the feed in the tank. The same vacuum system and cake formation process apply in the formation of the filter medium on the drum. Filtration and dewatering proceed in the same fashion as the rotary vacuum filter except that the cake forming over the filter is scraped off with a knife, which removes at the same time a thin layer of the filter medium (up to 0.8 mm). This allows to remove completely the filter cake from the filter medium and permits fresh exposure of the filtration medium to the slurry waste.

Advantages

- Fine solids can be removed, better than the standard vacuum filters.

Limitations

- Application of precoat requires up to one hour, making the process not truly continuous.

Filter press

The filter press consists of number of plates stacked either horizontally or vertically (see Fig. 2.11b). Each plate has a cavity on each site which is lined with a filter cloth. The surface of the cavity is corrugated to allow free drainage of the filtrate through the filter medium and to the filtrate discharge ports. The plates are held together by either hydraulic or mechanical force, and sealed with gaskets. During filtration, cake forms on the filter medium and eventually fills the chambers. At the end of the filtration cycle, the pressure holding the plate together is released and the plates are separated individually. Ideally the cake will be dry enough to drop freely into a collecting hopper. The filter cloth is washed and ready for another cycle.

Advantages

- Produces the driest cake of all dewatering processes.

Limitations

- Must be operated in batch mode.
- Process is labour-intensive.

Cost evaluation

The capital cost of a filter press system for a treatment capacity of 59.000 tonnes/year is estimated at $455,000 based on a detailed study (2) done in 1985 and indexed to 1994 Canadian dollars. The operating costs, including materials ($34,000), electricity ($10,600), labour ($21,000), maintenance ($22,700) and other ($22,700), can be translated to approximately $2/tonne of waste treated (various aqueous solutions and sludges).

Approval requirements

Filter press filtration will generate typically 150 kg/tonne of filter cake for disposal and near 1.05 tonne/tonne of aqueous stream with dissolved organics and salts (2).

Belt filter press

The belt filter press is a continuous sludge-dewatering process where a cake if formed under gravity and dewatered by mechanical compression between two filter belts (see Fig. 2.11c). The sludge or waste is fed on the top of the first moving belt where it is thickened by simple gravity and filtrate collected. The sludge is discharge to a second moving belt. The two belts move together and gradually converge, applying pressure to the sludge and dewatering the sludge further. Compression rollers under hydraulic pressure produce a low water content cake. The cake is finally discharged and the two belt sections are washed before returning to the beginning of the cycle.

Advantages

- Continuous process with relatively low labour and power requirements.

Limitations

- Poor quality of filtrate: 200-500 ppm suspended solids at the gravity stage; 500-2,000 ppm at the high pressure roller stage.
- Belt washwater generation rate as high as 70% to 100% of sludge feed rate.
- Total wastewater generation is high: combine wastewater (filtrate and backwash) typically 85% to 110% of sludge feed needs to be reprocessed for suspended solids.

2.11.3 CROSS-FLOW FILTRATION

Process principles

The liquid waste is circulated at high velocity through a porous tube. The solids concentration increases as the filtrate flows through the porous medium. The turbulent flow in the tube prevents the formation of a filter cake. In a continuous system, a small fraction of the recirculating stream (called reject) is bled off to maintain a constant solids concentration as new liquid waste is introduced in the recirculation loop.

Applicability and Efficiency

- Dewatering of slurries of 1-30% solids by weight.
- A common step in an integrated hazardous waste treatment system.

Advantages

- Certain type of filters (screen, vacuum, belt) can be operated in continuous mode.
- Most filter media are re-usable, except for the disposable cartridge filter type.
- Reduces weight of solids requiring further treatment.

Limitations

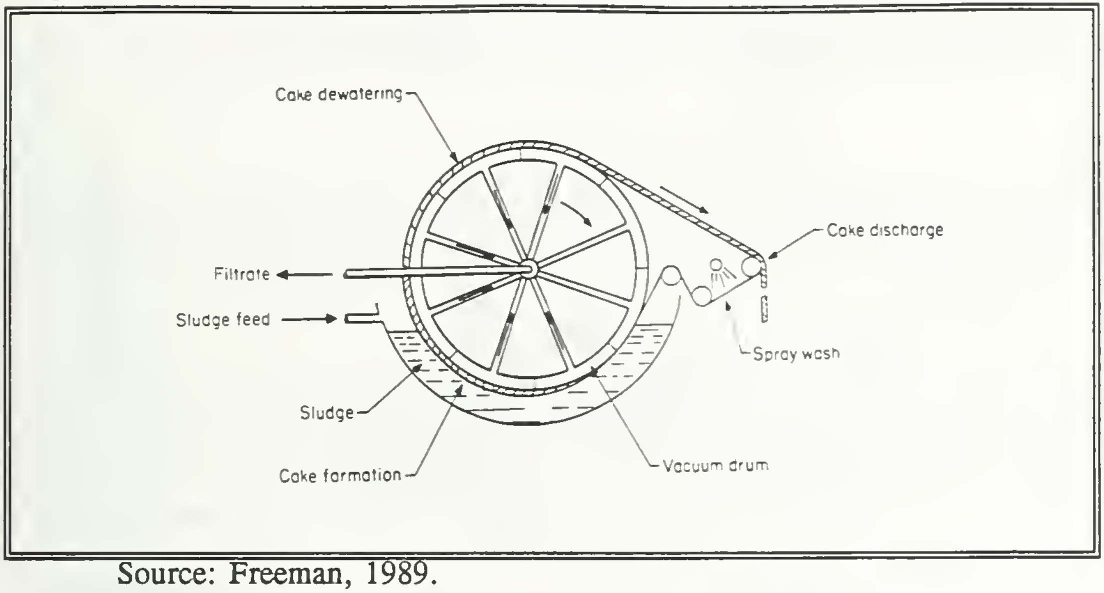
- Not applicable to contaminants dissolved in waste streams.
- Not applicable to highly viscous or gelatinous streams.

Reference

1. Freeman, H.M., 1989. Standard Handbook of Hazardous Waste Treatment and Disposal, McGraw-Hill, ISBN 0-07-022042-5.

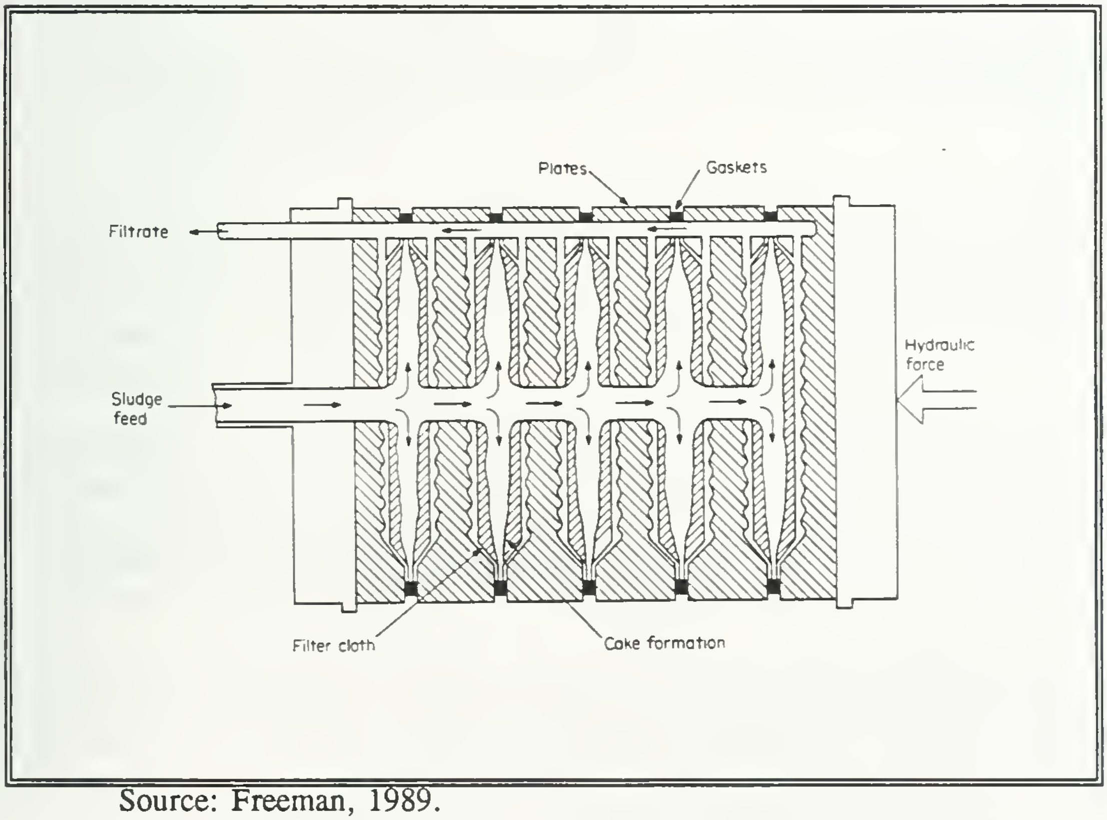
2. A.D. Little, 1985. Systems and technologies for treatment and disposal of special wastes in Ontario. Draft report to Ontario Waste Management Corporation, by Arthur D. Little of Canada Limited, February 8, 1985 (unpublished).

Figure 2.11a: Cross section of a Rotary Vacuum Belt Filter.



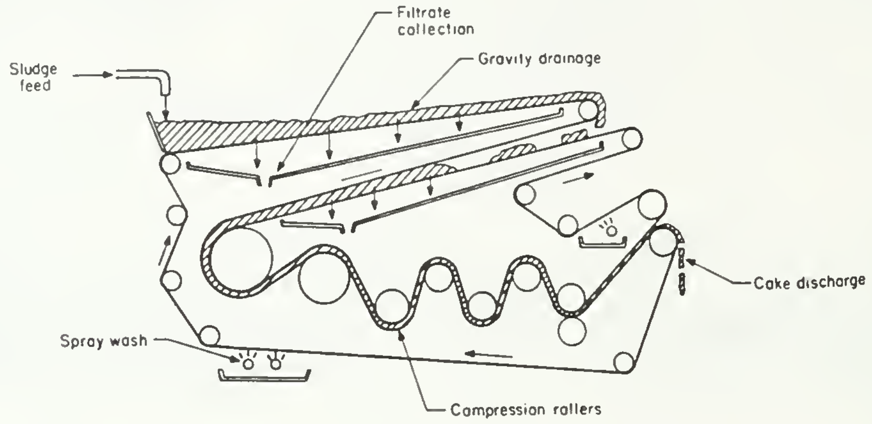
Source: Freeman, 1989.

Figure 2.11b: Cross section of Filter Press



Source: Freeman, 1989.

Figure 2.11c: Cross section of Belt Filter Press.



Source: Freeman, 1989.

2.12 FREEZE-CRYSTALLIZATION

Process summary

This process involves lowering the temperature of a liquid mixture until one of the compounds freezes. The solid and liquid fractions are then separated, resulting in a reduction or elimination of the crystallized compounds from the mixture.

Principle

The freeze-crystallization process allows to separate water from liquid hazardous wastes by cooling the solution until ice crystals form. Water normally crystallizes as pure ice. The ice is separated from the contaminated solution, therefore concentrating the waste.

Treatment process

There are 4 basic steps in the freeze-crystallization process (see Fig. 2.12a):

1) freeze and crystallize one (or more) material from the solution;
2) separate the crystals from the solution;
3) melt separated crystals;
4) transfer heat from the crystallizer to melter.

The waste feed enters a heat exchangers where the heat of the waste is exchanged with the cold of the product (melted ice) and the concentrated liquid waste. The crystallization is produced in the freezer using either of 2 methods: (1) by removing heat from the waste through a heat-transfer surface or (2) by direct contact of a refrigerant with the liquid waste.

The mixture of ice crystals and liquid waste is pumped to the crystal separator-washer. Crystals can be separated from the waste either by filtration, centrifugation or by wash columns. The ice must be washed to remove adhering liquid waste. The wash column design allows countercurrent washing and is therefore more efficient than the other separator designs.

The liquid waste from the separator is recycled to the freezer for further crystallization of residual water. The waste can also exit the system through the heat exchanger as a concentrated waste. The washed ice crystals are circulated through the melter. The fusion heat used for the melting of the crystal is used to condense the refrigerant of the freezer, and improve the energy efficiency of the system. In addition, the product (melted ice) can be passed through the feed heat exchangers to cool the incoming waste feed.

Applicability and Efficiency

- high efficiency in treated water: from 0.01 to 0.1% of the concentration of contaminants in the feed.

Advantages

- Energy-efficient process compared to distillation: heat of fusion of water (heat to melt ice to water) is only 15% of heat of vaporization (heat to vaporize water to steam).
- Pretreatment usually not required: process not affected by salts or organic materials.
- Emissions from the process are virtually non-existent.

Limitations

- Pilot testing usually required because limited process data (technology under development).
- High capital cost and low operating cost: expected lower life-cycle cost than other treatment technologies.
- Long-term operating and maintenance costs, and reliability are unproven.

Cost evaluation

The cost is typically $0.025 to $0.15 US per gallon of purified water, including equipment amortization (1), translating to between $8 to $53 Canadian dollars per tonne.

Approval requirements

Since the air emission from the process is virtually non-existent, air approval is limited to assurance of integrity of the refrigerant system in the freezer, melter and heat exchangers.

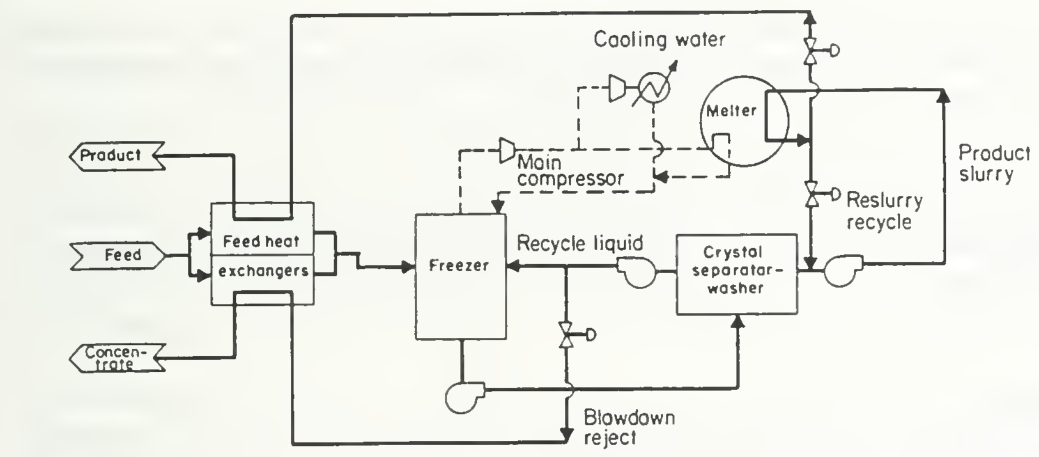
Water effluents are from the ice melter and should be of good quality unless the ice crystal washing system is operating poorly.

Waste effluents are from the crystal separator and the concentrate blowdown. These effluents are concentrated waste streams and require further treatment before disposal.

References

1. Freeman, H.M., 1989. Standard Handbook of Hazardous Waste Treatment and Disposal, McGraw-Hill, ISBN 0-07-022042-5.

Figure 2.12a: Process diagram of freeze-crystallization



Source: Freeman, 1989.

2.13 HEAVY MEDIA SEPARATION

Process summary

The separation of two solids is obtained by adding a liquid to the mixture which has a density that results in one solid floating to the liquids surface while the other solid sinks to the bottom.

Applicability and efficiency

- Applicable for separation of 2 solid materials having significantly different densities.
- Commonly used in the mining industry to separate ores from tailings.

Advantages

- Low energy requirement.

Limitations

- Possibility of dissolving solids
- Selective only on a broad range of densities.
- Introduce another material into the waste stream.

2.14 ION EXCHANGE

Process summary

In an ion exchange process the contaminating ion in a solution is removed and replaced by another less polluting ion, obtained from a contact resin.

Ion exchange is a process for treating inorganic wastes in solution. The process involves a chemical reaction in which mobile hydrated ions of a solid are exchanged, equivalent for equivalent, for ions of like charge in solution. The solid has an open, fish-net-like structure and the mobile ions neutralize the charged, or potentially charged, groups attached to the solid matrix. The solid matrix is termed the ion exchanger.

Ion exchange is normally not a disposal method for hazardous waste but rather a treatment method used to convert a hazardous waste into a form in which it can be reused. The process produces a residue which is less toxic than the original waste. Ion exchange is also used to remove hazardous wastes such as heavy metals from a solution and to concentrate them so that they can be treated. Recent advances in equipment and process design have allowed ion exchange to be applied to the purification of concentrated chemical solutions such as steel pickle liquors(2). The purified concentrate can be recycled to the process.

Process Description

Ion exchange resins act as solid, insoluble acids or bases which are capable of entering into chemical reactions in the same way as mineral or organic acids in solution but at a slower rate.

There are basically two types of ion exchange resins:

- cationic resins which exchange positively charged ions
- anionic resins which exchange negatively charged ions.

Cation exchangers

There are three types of cation exchange resins:

- strong acid cation resins
- weak acid resins
- chelating resins.

Strong acid cation resins have sulphonic acid groups which exchange cations over the entire pH range. For example, a strong acid ion exchange resin which is originally in the hydrogen form can exchange two hydrogen ions (H^+) for one copper ion (Cu^{++}), thus removing the copper from solution. The strong acid resins do not retain hydrogen tightly; they are, therefore, somewhat difficult to regenerate (replace the H^+ ions) using acid, usually requiring several times the theoretical dosage of acid to convert them back to the hydrogen form after exhaustion (i.e., after no more copper ions can be exchanged for hydrogen ions).

Ion exchange is reversible, so that the copper can be removed from the resin by regeneration with a moderately concentrated (about 10%) strong mineral acid to yield a more concentrated solution of the copper. In some cases it is possible to recycle the metal concentrate produced by regeneration.

Weak acid resins have carboxylic acid groups. The resins readily associate with hydrogen ions and, thus, regenerate easily with nearly stoichiometric quantities of acid. However, they do not function below a pH of about 4.

Chelating resins are very similar to weak acid resins. The principal feature of these resins is that they exhibit a high degree of selectivity for many toxic metals such as copper, mercury, nickel, and lead. The relatively slow kinetics of chelating resins necessitate the use of low flow rates and large resin inventories. They are also considerably more expensive than other resins and are not functional below a pH of about 3 or 4.

Anion exchangers

Strong base anion resins have quaternary ammonium groups which do not readily associate with hydroxyl ions (OH^-). They function over the entire pH range, but require an excess of strong base (usually sodium hydroxide) to regenerate. Strong base resins are capable of removing acids as well as splitting salts such as sodium chloride.

Weak base anion resins readily associate with hydroxyl ions resulting in high regeneration efficiencies. The disadvantage of weak base resins is that they function only under acidic conditions and are not capable of splitting salts.

Process designs

Ion exchange reactions are normally carried out with the resin in vertical columns in which the resin is "fixed". The resin is usually regenerated in place. Continuous ion exchange systems have been developed but are expensive and complex. Their use has, therefore, been restricted to very large primary metals (mining) applications.

Several different fixed bed ion exchange equipment types with different column and process designs are being used in the treatment of hazardous wastes.

The design can be grouped into four basic classes of design:

- concurrent,
- countercurrent,
- short bed, and
- mixed bed.

Concurrent Fixed Bed

This is the least efficient design but is the least costly and is also simple to operate. There are vast amounts of data available on the operation of these systems in the water treatment industry.

There are four steps in the concurrent ion exchange cycle:

- service,
- backwash,
- regeneration, and
- displacement and rinse.

During the service step, the solution to be treated is fed to the column by passing it downward through the resin column which is ⅔ filled with resin to a height of 60 to 150 cm. The service step continues until leakage of the ion being removed reaches an unacceptable level at the bottom of the column. Flow rates during this step range from 8 to 40 bed volumes per hour.

The second step is backwash. During this step, water is passed upflow through the column at a flow sufficient to fluidize the resin bed 50 to 100%. This serves to reclassify the resin, to avoid channelling, solution and to remove any suspended solids which may have filtered out on the resin bed during service.

The third step is regeneration. This is normally accomplished by passing a dilute (1 to 5 normal) solution of either acid (for cation exchange) or caustic (for anion exchange) down through the column.

The forth step is displacement and rinse. Excess regenerant is displaced from the column with water at a slow flow rate. After this, the resin is rinsed with water at high flow to remove the last trace of chemical from the resin.

Countercurrent Fixed Bed

The countercurrent method uses service flow in the direction opposite to the regeneration flow. This provides higher uptake and regeneration efficiencies. It also produces less chemical waste and more concentrated recovered products on regeneration. These advantages are achieved because the solution being treated contacts the most highly regenerated part of the ion exchange bed as it exits from the bed; they also make this system well suited to wastewater treatment applications.

This system is more complex than the concurrent system because special techniques must be used to prevent the ion exchange bed from fluidizing during the upflow step. The special techniques used in this method have been patented and significantly increase the cost of this system.

Short Bed

A patented short bed system, Recoflo™, was introduced in the early 1970s primarily for wastewater and chemical recovery applications. Some are used in the metal finishing industry for recovery of heavy metals and waste acid. The system uses countercurrent regeneration, fine mesh ion exchange resins, low exchanger loadings, fast cycle times and short resin beds (7.5 - 61 cm).

This system has the ability to treat and produce relatively concentrated as well as dilute solutions. It also has the advantages of efficient regeneration, compact size, decreased regenerant wastes and semicontinuous operation through extremely short off-stream times.

Mixed Bed

Two different types of resins, usually a mixture of strong acid cation resin and strong base anion resin, are used in the mixed bed system and are installed in a single column. When water is passed through the column, the deionization which occurs is very nearly complete. Mixed beds are useful for producing effluents of exceptionally high purity although regeneration is quite inefficient.

Following the service cycle, the resins are separated by backwash. Since anion exchange resins have a lower density than cation exchange resins, hydraulic separation into two layers occurs. This enables subsequent regeneration of each resin separately. Air agitation then remixes the resins. Alternatively, the resins can be removed from the column and regenerated externally.

Applicability and efficiency

- Treatment of hazardous wastes from the electroplating industry is one of the largest applications of ion exchange technology for hazardous waste treatment.
- Treatment of cooling tower blowdown by ion exchange to remove chromate ions has been practised for some time.
- Ion exchange is used to purify and recover strong mineral acids such as sulphuric, hydrochloric, nitric and phosphoric used in processes such as the pickling, etching and anodizing of a variety of metals.

Advantages

- Ion exchange can convert a hazardous waste into a form in which it can be reused.
- The process produces a residue which is less toxic than the original waste.
- Ion exchange is also used to remove hazardous wastes such as heavy metals from a solution and to concentrate them so that they can be treated.
- Ion exchange to be applied to the purification of concentrated chemical solutions such as steel pickle liquors. The purified concentrate can be recycled to the process.

Limitations

- Chemical wastes are produced if excess ion exchange resin regenerant is required.
- There are limitations on the concentrations of what can be treated and produced.
- Down time is required for regeneration.
- Resins cannot yet be made which are specific to a particular substance.
- Ion exchange resins are prone to fouling by some organic substances.

Cost evaluation

The capital cost for a treatment capacity of 46,000 tonnes/year is estimated at $740,000, based on a detailed study (3) done in 1985 and indexed to 1994 Canadian dollars. The operating costs, including materials ($22,700), electricity ($13,300), labour ($21,100), maintenance ($37,000) and other ($37,000), can be translated to approximately $5/tonne of waste treated (various aqueous solutions with metals).

Approval requirement

An estimated 2 kg/tonne of spent media will be generated from ion exchange treatment. An estimated 25 kg/tonne of acidic (or basic) aqueous stream with dissolved solids will be generated from regeneration operations (3).

Reference

1. Freeman, H.M., 1989. Standard Handbook of Hazardous Waste Treatment and Disposal, McGraw-Hill, ISBN 0-07-022042-5.
2. A.D. Little, 1986. Technologies and systems for treatment and disposal of special wastes in Ontario. Final report to Ontario Waste Management Corporation, by Arthur D. Little of Canada Limited, October 2, 1986.
3. A.D. Little, 1985. Systems and technologies for treatment and disposal of special wastes in Ontario. Draft report to Ontario Waste Management Corporation, by Arthur D. Little of Canada Limited, February 8, 1985 (unpublished).

2.15 IRRADIATION

Process description

Various forms of radiation can be used to provide the energy needed to break chemical bonds resulting in a detoxification of a material. Irradiation is provided by electron beams, nuclear radiation, radio waves, lasers and microwaves. Nuclear irradiation can also be used to kill microorganisms in biomedical wastes.

Applicability and efficiency

- Used in destruction of microbes, pathogens and viruses found in hazardous wastes (mostly pathological wastes).
- Specific application for "international garbage" (from airports and seaports), due to potential diseases.
- Other applications: municipal sewage sludge and food sterilization.

Advantages

- Environmentally clean process: no chemical used, no gas emission, no toxic reactions.
- Costs competitive with existing waste management methods.
- Low energy requirement.

Limitations

- No volume deduction of the waste.
- High capital requirement.
- Not effective for metals and toxic chemicals.

2.16 LIQUID-LIQUID EXTRACTION

Process summary

A mixture of two liquids is separated by adding a third liquid. The added liquid dissolves one of the mixed materials and create a liquid that is immiscible with the mixture. The new liquid is then separated from the solution. This process is also referred to as solvent extraction or simply extraction.

Process description

Liquid-liquid extraction is a specific application of the general technology called solvent extraction (see section 2.21). The liquid solvent is applied to liquid waste mixtures only.

The processes used in liquid-liquid extraction are similar to the solvent extraction processes.

Liquid-liquid extraction is conducted in 4 basic steps:

1. contact of solvent and waste in a reactor;
2. separation of extract and raffinate;
3. treatment of extract;
4. treatment of raffinate.

There is a wide range of equipment available to bring the solvent and the waste in close contact for extraction. At the simple end of the range, single-stage mixers and settlers are used. At the more elaborate end, multi-stage extraction columns are run in cross-current mode, or more commonly in a conter-current mode (4).

The extractor design includes provision for separating the extract and raffinate.

The extract (solvent and contaminant mixture) normally undergo further treatment. The solvent is normally purified for recycling, due to economic benefits. The contaminant may also have some economic values. Separation of the solvent and contaminant is done in various ways, depending on the physical and chemical properties of the extract:

- air or steam stripping for volatile contaminants;
- distillation or evaporation for volatile solvent;
- second solvent extraction for removal of phenols from aromatic solvents.

The raffinate (waste and residual contaminant/solvent mixture) may contain sufficient concentration of solvent to justify recovering it for recycling. Even if recovery is not practical, the raffinate may require further treatment before disposal, using methods such as carbon/resin adsorption, activated sludge or other biodegradation methods, or air/steam stripping.

Applicability and efficiency

- Principal application in phenols removal in wastewaters from petroleum refinery, coke-oven and phenol-resin plant operations.
- Removal efficiency ranging typically from 90% to 98%, and can exceed 99% in some applications with the use of special equipment.

Advantages

- Lower energy requirements compared to other processes such as distillation.
- Limited requirements for materials since the solvent can be re-generated and re-used.

Limitations

- Appropriate solvent difficult to find: requirements include high selectivity, high saturation solubility for the contaminant, low solubility of the solvent in the feed material.

Cost evaluation

The capital cost for a treatment capacity of 4,000 tonnes/year is estimated at $385,000, based on a detailed study (3) done in 1985 and indexed to 1994 Canadian dollars. The operating costs, including materials ($65,500), electricity ($25,200), labour ($42,200), maintenance ($19,300) and other ($19,300), can be translated to approximately $40/tonne of waste treated (various aqueous solutions).

Approval requirement

Liquid-liquid extraction processes can be operated in totally enclosed conditions. If the system design is not closed, solvent gases can be a source of air emission. The extract (mixture of solvent and contaminants) is normally treated to recover valued materials, but it may also be burned as fuel or simply incinerated.

An estimated 50 kg/tonne of extracted organics will be generated from various aqueous solution with less than 10% organic residues (3).

Reference

1. Freeman, H.M., 1989. Standard Handbook of Hazardous Waste Treatment and Disposal, McGraw-Hill, ISBN 0-07-022042-5.

2. A.D. Little, 1986. Technologies and systems for treatment and disposal of special wastes in Ontario. Final report to Ontario Waste Management Corporation, by Arthur D. Little of Canada Limited, October 2, 1986.

3. A.D. Little, 1985. Systems and technologies for treatment and disposal of special wastes in Ontario. Draft report to Ontario Waste Management Corporation, by Arthur D. Little of Canada Limited, February 8, 1985 (unpublished).

4. Kirk-Othmer, Encyclopedia of Chemical Technology, Third Edition, 1980, John Wiley & Sons Ed., Volume 9, pp. 672-721.

2.17 OIL/WATER SEPARATION

Process Description

Oil/water mixtures are allowed to separate as a result of the oil being lighter than the water resulting in the oil floating on top of the water.

Applicability and efficiency

- Applicable to wastes containing immiscible liquids having different densities (eg. oil and water).
- Oil/water emulsion can be broken by acidification of the mixture and enhance the process efficiency.
- Other factors affecting the efficiency: flow rate, temperature.

Advantages

- Mobile separators are commercially available.

Limitations

- Used as a pre-treatment process only for oily wastes.

2.18 REVERSE OSMOSIS / ULTRAFILTRATION

Process summary

A sheet of membrane material separates the contaminated liquid from the uncontaminated liquid. By applying pressure to the contaminated liquid, the liquid will pass through the membrane leaving behind a more concentrated contaminated liquid. The membrane for reverse osmosis (RO) contains openings smaller than the ones from the ultrafiltration membrane so only smaller molecules will pass through the RO membrane.

Process principle

Osmosis occurs when a semi-permeable membrane separates two solutions with different contaminant concentrations. Pure water will flow through the membrane from the less concentrated solution to the concentrated solution, establishing an equilibrium between the two sides of the membrane. In reverse osmosis conditions, pressure is applied to the more concentrated solution to reverse the normal osmotic flow, causing pure water to move from the concentrated solution to the less concentrated solution. The effect is to increase the contaminant concentration in the concentrated side (called concentrate) and dilute the concentration in the less contaminated side (called permeate).

Process description

Reverse osmosis and ultrafiltration both use semipermeable membranes to remove a contaminant from a liquid waste material. The end products are two streams, one with a higher concentration of pollutant and a larger stream with a lower concentration. The resultant streams are then better able to be recycled or to be disposed of.

Reverse osmosis is used primarily to concentrate inorganic contaminants. Ultrafiltration is used primarily for the separation of organic compounds. The two processes are essentially the same in that the pressurized liquid to be treated flows through the membrane with one part of the liquid mixture passing through the membrane while another part will not pass through. The difference between the two is that reverse osmosis membranes are designed to allow water to pass through while the ultrafiltration membranes are designed to allow the passage of materials under a specific molecular size.

The equipment configuration and the membranes used are designed specifically for the contaminated stream being treated. Frequently, pretreatment is required in order for the membrane process to work efficiently and economically. Such treatments often include pH adjustment and suspended solids reduction.

As noted above, reverse osmosis is used primarily for the treatment of inorganic ion contaminants. Normally, if the appropriate membrane separates a water stream from a waste stream, the water would cross the membrane into the waste stream thus reducing the concentration of the contaminant. This is caused by the natural osmotic pressure that exists between two liquids of different ionic concentration.

In reverse osmosis, the contaminant side of the membrane is physically pressurized to overcome the osmotic pressure. This results in the water flowing in the opposite direction, from the waste side to the water side. The resultant loss of water in the contaminant side increases the waste inorganic ion concentration.

Since osmotic pressure increases with ion concentration, water removal will only continue until osmotic pressure counter balances the physical pressure. This naturally occurring limit is reached generally at an inorganic ion concentration of 100,000 mg/L.

Membrane characteristics include:

- Primarily made from cellulose acetate, aromatic polyamides thin-film composites.

- The membranes can be shaped in a number of different configurations, sometimes based on equipment supplier's unique design and sometimes on waste/membrane characteristics such as need to clean off one side of the membrane.

- Performance of a membrane is generally specified by the flow rate through the membrane (flux rate), proportion of waste feed flow left on exit from unit (conversion rate) and the success of the membrane in preventing the waste ions from passing through (rejection).

Applicability and efficiency

- Maximum achievable concentration of salt in solute (reject stream or concentrate) is 100,000 mg/L due to osmotic-pressure limitations.

Advantages

- The waste stream has greater potential for reuse in the manufacturing process or is more likely to have the inorganics recycled.

- No energy intensive change from a solid to a liquid or a liquid to a gas is involved.
- Reverse osmosis units are relatively inexpensive on a capital cost basis.
- Purity of recovered water is relatively high.
- Short term fouling of the membrane, caused by accumulation of cakes on the surface membrane, can be corrected by back-flushing (9).

Limitations

- Membranes and their configuration are generally specific to the waste type and flow rate (modular nature of equipment compensates for the sensitivity to flow rate).
- Membranes can become coated by oils or solids thus significantly reducing the reverse osmosis throughput.
- Long term fouling, caused by adsorption of organic compounds on the membrane surface and in the pores, is often hydraulically irreversible (9).
- For ultrafiltration, efficiency is limited to molecular weights between 500 and 1,000,000.
- Membranes limitations: 30-80 C°, tolerate low or no chlorine (0-100 ppm).

Cost evaluation

In a research project funded by MOEE(2), the capital and operation costs for treating landfill leachate by reverse osmosis was estimated as ranging from \$1.30 to \$1.97/kL (1991 Canadian dollars per 1,000 litres) for plant capacity ranging from 165 kL/day to 55 kL/day. The capital cost is based on a 10 year amortization, at 11%. This cost evaluation compares well with OWMC earlier estimate of near \$2/tonne for operating costs of 17,000 tonne/yr capacity (7).

A recent reverse osmosis design, developed by Rochem Separation Systems (California), has been demonstrated and implemented in some 40 US plants over the last 7 years(4-6). The service price (i.e. Rochem's price to provide this treatment to a client) was quoted at US\$0.03/USgal.(3), translating to C\$10.80/kL.

Approval requirements

Treatment by reverse osmosis is expected to generate 250 kg/tonne of aqueous stream with 3,000 ppm dissolved solids and 750 kg/tonne of filtrate solution at less than 500 ppm dissolved solids (8).

References

1. Freeman, H.M., 1989. Standard Handbook of Hazardous Waste Treatment and Disposal, McGraw-Hill, ISBN 0-07-022042-5.

2. MOEE, 1991. Field demonstration of membrane technology for treatment of landfill leachate, RAC Project No. 439c, December 1991.

3. MOEE, 1995. Treatment technologies for landfill leachates. Report prepared by Science and Technology Branch. January 1995. PIBS 3332E. ISBN 0-7778-3731-5.

4. Rochem, 1995. Technical presentation by Russell Pullan, Rochem Separation Systems Inc. (California) to STB/MOEE staff, August 22, 1995.

5. USEPA, 1994. Proceedings. Fifth forum on innovative hazardous waste treatment technologies: domestic and international. Chicago, Illinois, May 3-5, 1994. EPA/540/R-94/503. p.180.

6. USEPA, 1995. 21st annual RREL research symposium. Abstract proceedings. April 1995. EPA/600/R-95/012. p.145-148.

7. A.D. Little, 1986. Technologies and systems for treatment and disposal of special wastes in Ontario. Final report to Ontario Waste Management Corporation, by Arthur D. Little of Canada Limited, October 2, 1986.

8. A.D. Little, 1985. Systems and technologies for treatment and disposal of special wastes in Ontario. Draft report to Ontario Waste Management Corporation, by Arthur D. Little of Canada Limited, February 8, 1985 (unpublished).

9. Clark, Mark M., 1995. Fouling of ultrafiltration membranes by natural waters. Abstracts. World '95 World Environmental Congress. London, Ontario. September 17-22, 1995.

10. Kirk-Othmer, Encyclopedia of Chemical Technology, Third Edition, 1980, John Wiley & Sons Ed., Volume 23, pp. 439-461.

2.19 SCREENING

Process summary

The separation of materials is done by passing a waste mixture across a screen where the size of the openings in the screen has been selected to separate one type of coarse material from the finer ones.

Process description

Screening is usually the first pre-treatment step when the treatment technology requires specific conditions for the waste (i.e. limitation in size for granular waste or limitation in quantity of suspended particulates for aqueous waste).

Screening equipments can have stationary or moving screen decks. Moving screen decks can be designed as rotating cylinders (trommels) or vibrating surfaces. The most popular design is the inclined vibrating screen (Figure 2.19a). Vibration is produced typically by circular motion in the a vertical plane of 3-12 mm at 700-1000 cycles per minute. High speed screening can operate at 3600 cycles.

Applicability and efficiency

- Usually considered as a pre-treatment to many hazardous waste streams.

Advantages

- Economical pre-treatment process.

Limitations

- Not specific to any types of contaminants.

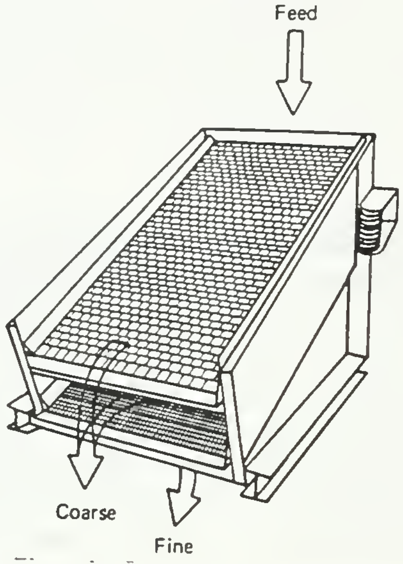
Approval requirements

Screening does not reduce the volume or toxicity of the hazardous waste. Air emissions are possible if the very fine segment of the waste is not controlled and collected properly.

References

1. Kirk-Othmer, Encyclopedia of Chemical Technology, Third Edition, 1980, John Wiley & Sons Ed., Supplement Volume, pp. 851-871.

Figure 2.19a: inclined vibrating screen.



Source: Kirk-Othmer, 1980.

2.20 SEDIMENTATION

Process summary

Materials with different densities are separated by allowing the heavier material to settle to the bottom of a container while the lighter material floats at the top.

Process description

Sedimentation is the simplest and most economical of all the reparation processes. Its drawback is that it requires long period of time and large holding tanks or basins. This process is widely used in treatment of municipal and industrial wastewater, as well as treatment of aqueous hazardous wastes (1).

Sedimentation can be enhanced in some cases by pre-treating the aqueous waste with flocculation agents. Flocculants create attractive forces between suspended particulates which coalesce and precipitate faster than individual particulates.

Precipitation is different than sedimentation or flocculation. Precipitation involves chemical reactions which cause the separation of heavy metals and fluorides from a solution as insoluble solid particles. Flocculation and/or sedimentation may be used after precipitation to concentrate and remove the suspended solids (2).

Applicability and efficiency

- Restricted to solids which are denser than water.
- Not suitable for wastes containing emulsified oils.
- Efficiency dependant on depth/surface of basin, settling time (holding time), solid particle size, and flow rate.

Advantages

- Economical pre-treatment process.

Limitations

- Limited to aqueous wastes with low viscosity.
- Large basin required for suitable settling time.

Cost evaluation

The capital cost for a treatment capacity of 59,000 tonnes/year is estimated at $600,000, based on a detailed study (2) done in 1985 and indexed to 1994 Canadian dollars. The operating costs, including materials ($2,100), electricity ($6,600), labour ($42,200), maintenance ($30,000) and other ($30,000), can be translated to approximately $2/tonne of waste treated (various aqueous solutions).

Approval requirements

Flocculation and sedimentation will typically generate 180 kg/tonne of slurry for further treatment (filtration or centrifugation) and some 900 kg/tonne of aqueous stream with dissolved salts and suspended solids (2). There is no air emission since only non-volatile wastes are treated.

References

1. Kirk-Othmer, Encyclopedia of Chemical Technology, Third Edition, 1980, John Wiley & Sons Ed., Volume 24, pp. 410-414.

2. A.D. Little, 1985. Systems and technologies for treatment and disposal of special wastes in Ontario. Draft report to Ontario Waste Management Corporation, by Arthur D. Little of Canada Limited, February 8, 1985 (unpublished).

3. A.D. Little, 1986. Technologies and systems for treatment and disposal of special wastes in Ontario. Final report to Ontario Waste Management Corporation, by Arthur D. Little of Canada Limited, October 2, 1986.

2.21 SOLVENT EXTRACTION

Process Summary

A solvent, added to a waste stream, will make certain contaminants more soluble in the solvent solution. The mixture of solvent and contaminants is later separated from the waste mixture. Solvent and contaminants can also be separated to re-use the solvent.

Solvent extraction is a broad term that includes more specific technologies such as liquid-liquid extraction (section 2.16), liquid ion exchange (section 2.14) and supercritical extraction (section 2.23). These processes are reviewed in other sections of this document.

Solvent extraction principles

Solvent extraction is a thermodynamic process which depends on the equilibrium of the feed (waste) and the solvent, once they are mixed together. Simply stated, the contaminants in the waste are miscible (at different levels) with both the solvent and the waste. The solvent however has a higher affinity to mix with the contaminants than with the waste mixture itself, thus reducing the concentration of contaminants in the waste. The other quality of the solvent is its low solubility with the waste, making it easier to separate the two solutions after treatment. Finally, the mixture solvent/contaminant should be easily separable, in order to re-use the solvent and manage the concentrated contaminants.

In thermodynamic terms, the level of miscibility of the contaminant is expressed by the partition coefficient (or distribution coefficient) K_C:

$$K_C = X_{CS} / X_{CF}$$

where X_{CS} is the weight fraction of the contaminant in the solvent and X_{CF} is the weight fraction of the contaminant in the feed (waste). This distribution coefficient defines the maximum transfer of the contaminant from the feed to the solvent. If additional removal of the contaminant from the waste is required, multiple contacts are required. The higher the distribution coefficient, the less solvent is required and less multiple contacts are required.

The selected solvent should have the following properties with respect to the waste and the contaminant of concern:

1. High selectivity of the mixtures: in the extraction process we want the concentration in the extract (solution of contaminant and solvent) to be as high as possible compared to the concentration in the raffinate (waste depleted of the contaminant after treatment). This selectivity is expressed as the ratio K_C/K_F. A ratio of 1 indicates that no extraction will occur. The ratio must be greater than 1, and the larger the better.

2. High solubility of the contaminant in the solvent: the solvent must have the ability to dissolve large quantities of the contaminant before reaching saturation.

3. Low solubility of the solvent in the waste: the extract and the raffinate are eventually separated from the extraction vessel. For economic and environmental reasons, the residual solvent needs to be as low as possible in the waste: extracting solvents are often expensive and high concentration of solvent in the raffinate would make it unsuitable for direct disposal without further treatment.

Treatment process

Solvent extraction is conducted in 4 basic steps:

1. contact of solvent and waste in a reactor;
2. separation of extract and raffinate;
3. treatment of extract;
4. treatment of raffinate.

There is a wide range of equipment available to bring the solvent and the waste in close contact for extraction. At the simple end of the range, single-stage mixers and settlers are used. At the more elaborate end, multi-stage extraction columns are run in crosscurrent mode, or more commonly in a contercurrent mode.

The extractor design includes provision for separating the extract and raffinate.

The extract (solvent and contaminant mixture) normally undergo further treatment. The solvent is normally purified for recycling, due to economic benefits. The contaminant may also have some economic values. Separation of the solvent and contaminant is done in various ways, depending on the physical and chemical properties of the extract:

- air or steam stripping for volatile contaminants;
- distillation or evaporation for volatile solvent;
- second solvent extraction for removal of phenols from aromatic solvents.

The raffinate (waste and residual contaminant/solvent mixture) may contain sufficient concentration of solvent to justify recovering it for recycling. Even if recovery in not practical, the raffinate may require further treatment before disposal, using methods such as carbon/resin adsorption, activated sludge or other biodegradation methods, or air/steam stripping.

Applicability and efficiency

- Includes liquid/liquid extraction process (see above) and leaching (solid/liquid extraction).
- Principal application in phenols removal in wastewaters from petroleum refinery, coke-oven and phenol-resin plant operations.
- Removal efficiency ranging typically from 90% to 98%, and can exceed 99% in some applications with the use of special equipment.

Advantages

- Lower energy requirements compared to other processes such as distillation.
- Limited requirements for materials since the solvent can be re-generated and re-used.

Limitations

- Appropriate solvents are difficult to find: requirements include high selectivity, high saturation solubility for the contaminant, low solubility of the solvent in the feed material.

Cost evaluation

The capital cost for a treatment capacity of 4,000 tonnes/year is estimated at $385,000, based on a detailed study (3) done in 1985 and indexed to 1994 Canadian dollars. The operating costs, including materials ($65,500), electricity ($25,200), labour ($42,200), maintenance ($19,300) and other ($19,300), can be translated to approximately $40/tonne of waste treated (various aqueous solutions).

Approval requirement

Solvent extraction processes can be operated in totally enclosed conditions. If the system design is not closed, solvent gases can be a source of air emission. The extract (mixture of solvent and contaminants) is normally treated to recover valued materials, but it may also be burned as fuel or simply incinerated.

An estimated 50 kg/tonne of extracted organics will be generated from various aqueous solution with less than 10% organic residues (3).

Reference

1. Freeman, H.M., 1989. Standard Handbook of Hazardous Waste Treatment and Disposal, McGraw-Hill, ISBN 0-07-022042-5.

2. A.D. Little, 1986. Technologies and systems for treatment and disposal of special wastes in Ontario. Final report to Ontario Waste Management Corporation, by Arthur D. Little of Canada Limited, October 2, 1986.

3. A.D. Little, 1985. Systems and technologies for treatment and disposal of special wastes in Ontario. Draft report to Ontario Waste Management Corporation, by Arthur D. Little of Canada Limited, February 8, 1985 (unpublished).

4. Kirk-Othmer, Encyclopedia of Chemical Technology, Third Edition, 1980, John Wiley & Sons Ed., Volume 9, pp. 672-721.

2.22 STEAM STRIPPING

Process summary

Steam is used to vaporize volatile material in a liquid or a solid. The evaporated material is removed from the mixture by the steam/air flow.

Process principle

Steam stripping is essentially a distillation process, where there exists a vapour-liquid equilibrium between water and the organic contaminants. This vapour-liquid equilibrium must be known, empirically or estimated, to design properly the steam stripping system.

Process design

Steam stripping can be described as a continuous fractional distillation process without rectification. These terms have been defined and explained in the distillation process (see Section 2.7). The waste feed is introduced at the top of a packed or tray tower (see Fig. 2.22a). The steam enters the bottom of the tower, unlike the continuous distillation tower where steam is generated from the reboiler. For aqueous waste, the bottom residue of the tower is a relatively clean product and the vapour at the top of the tower is a mixture of organic vapour and steam. The overhead steam is condensed in heat exchanger and collected in a decanter where immiscible organic and aqueous phases are gravity separated. If the aqueous phase still contains miscible organic contaminants, it is recombined with the feed and returned to the top of the stripper. The organic phase can be recovered for re-use as a solvent or a fuel. The condensed overhead product is a concentrated aqueous solution which needs further treatment or may be recycled.

Applicability and efficiency

- Efficiency better than 99% for volatile/semivolatile organics in concentration up to several percents.
- Applicable to water-immiscible solvents from streams such as oil/grease, paint solids, polymeric resins, paper mill wastewaters, pesticides and pentachlorophenol waste.

Advantages

- More widely applicable than air stripping: can effectively remove less volatile or more soluble organics than air stripping.

Limitations

- Pretreatment required to remove suspended solids.
- Not applicable for removal of non-condensible organics such as vinyl chloride.
- Energy demanding (production of steam).

Cost evaluation

The capital cost for a treatment capacity of 1,500 tonnes/year is estimated at $52,600, based on a detailed study (3) done in 1985 and indexed to 1994 Canadian dollars. The operating costs, including electricity ($600), steam ($4,400), labour ($10,500), maintenance ($2,600) and other ($2,600), can be translated to approximately $12/tonne of waste treated (various aqueous solutions).

Approval requirement

An estimated 10 kg/tonne of volatile organics and ammonia will be generated from steam stripping aqueous solution less that 10% organic residues (3).

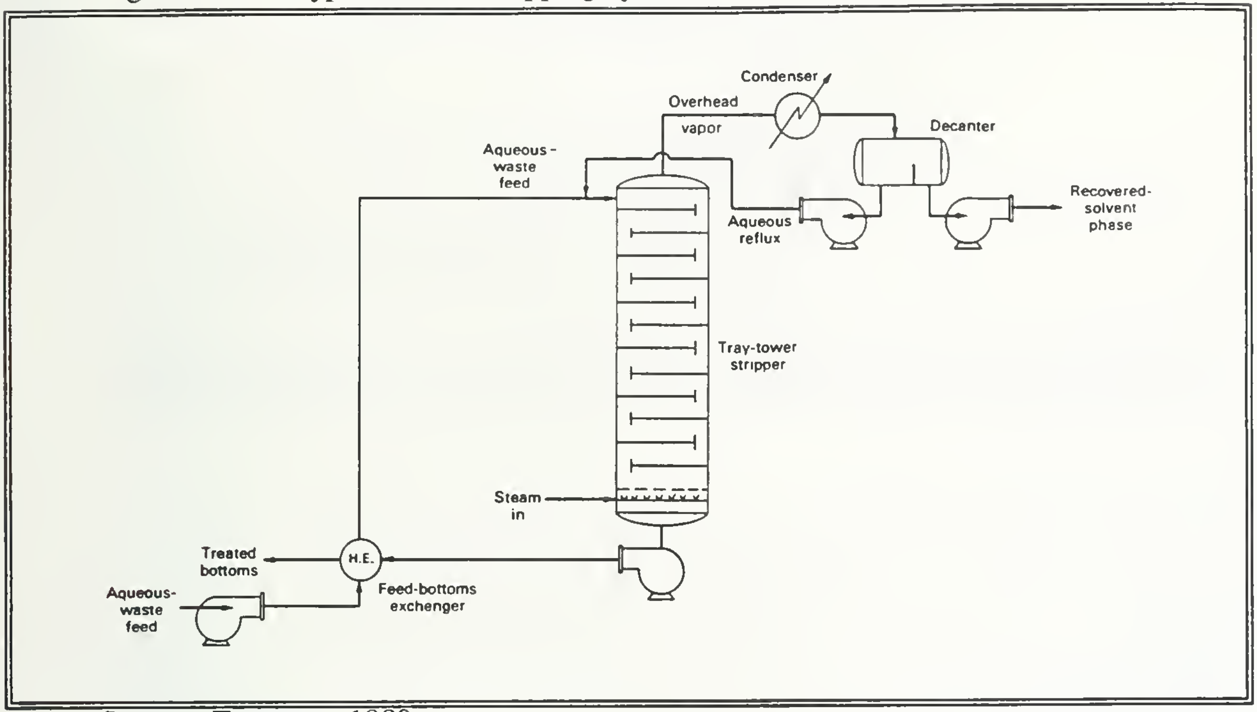
Reference

1. Freeman, H.M., 1989. Standard Handbook of Hazardous Waste Treatment and Disposal, McGraw-Hill, ISBN 0-07-022042-5.

2. A.D. Little, 1986. Technologies and systems for treatment and disposal of special wastes in Ontario. Final report to Ontario Waste Management Corporation, by Arthur D. Little of Canada Limited, October 2, 1986.

3. A.D. Little, 1985. Systems and technologies for treatment and disposal of special wastes in Ontario. Draft report to Ontario Waste Management Corporation, by Arthur D. Little of Canada Limited, February 8, 1985 (unpublished).

Figure 2.22a: Typical steam stripping system



Source: Freeman, 1989.

3. THERMAL/INCINERATION PROCESSES

3.0 INTRODUCTION

Conventional incineration can be divided into two categories:

- hazardous waste incinerators,
- co-treatment processes,

Currently, there are five (5) basic types of incinerators available for the destruction of liquid, solid and gaseous hazardous waste. Some variations of each type are also used. Basic types of incinerators are:

1) rotary kilns (section 3.1);
2) fixed hearth incinerator (section 3.2);
3) liquid injection incinerator (section 3.3);
4) fluidized bed incinerator (section 3.4);
5) direct flame incinerator (section 3.5).

Co-treatment processes are relatively new applications of conventional industrial combustion systems in which destruction of hazardous and industrial wastes is accomplished during the routine operation of the process equipment. Examples of co-treatment processes include:

1) High efficiency boilers

High efficiency boilers are basically designed to burn coal, oil or natural gas and produce steam for process heating or steam-generated electricity. Residence times in these units are in the range of 1.0 to 3.7 seconds with combustion zone temperatures of 1430-1675°C.

High efficiency boilers can be used to incinerate waste oils as well as oils lightly contaminated with PCBs and solvents. The waste material should be diluted with fuel oil and fed directly into the combustion zone of the boiler. In the U.S., particular interest has been shown in using high efficiency boilers to burn oils contaminated with up to 500 ppm PCBs. Factors that must be considered before a boiler is selected for PCB destruction include: boiler firing configuration, type of fuel and residence time. Boilers with horizontally opposed fuel guns generally provide greater flame turbulence which promotes better mixing and a higher combustion efficiency than tangentially fired units. Boilers fired with coal are usually constructed of HCl resistant materials due to the presence of chlorides in the coal and thus are more resistant to HCl from PCB destruction. However, using boilers as incinerators can present operating problems; for example, incomplete destruction of the waste material can occur because of channelling or by-passing within the boiler.

2) Kilns (cement or lime production)

Portland cement is produced by calcining raw materials containing calcium, silicon, aluminum and iron in a high temperature oil or coal fired rotary kiln. Other industrial kiln operations include lime and lightweight aggregate production. Kilns are also used in Kraft pulp and paper mills for lime reclamation. Typical temperatures in the gases in these kilns are above 1000°C for at least several seconds. A cement kiln's maximum gas temperature could be 1800°C. Lime kilns operate at maximum temperatures of 1000-1300°C while lightweight facilities operate at average temperatures of 1050-1150°C.

Regardless of the kiln operation, these processes require high temperatures and long residence times for the hot gases. Both of these design features are required for good combustion of hazardous wastes.

Limited test data indicates mixed performance levels; however, performance deficiencies were usually attributable to the inability of control equipment to handle increased dust loads.

Reference

1. Freeman, H.M., 1989. Standard Handbook of Hazardous Waste Treatment and Disposal, McGraw-Hill, ISBN 0-07-022042-5.

2. Rickman, W.R., 1991. Handbook of incineration of hazardous wastes. CRC Press, 1991.

3.1 ROTARY KILNS

Process summary

A slowly rotating and slightly incline cylinder is heated to high temperatures and various wastes are introduced in the reactor for incineration.

Treatment process

The unit is a slowly rotating refractory-lined cylinder mounted at a slight incline to horizontal (see Figure 3.1a). Rotary kilns generally have length to diameter ratios between 2:1 and 10:1. The shell rotates at a peripheral speed in the range of 0.3 to 3 metres per minute. The rotation continually mixes and exposes the waste with combustion air thereby improving the combustion efficiency. Combustion temperatures vary according to the characteristics of the waste material but are generally in the range of 800-1200 °C. Retention time can range from 0.1 to 2 seconds for gases and liquids, and can reach as high as several hours for solids.

The primary function of the kiln is to convert solid or liquid wastes into gases. This conversion occurs through a series of volatilization, destructive distillation and partial combustion reactions. Since these gases still contain organic components, further oxidation is required. This occurs in a secondary chamber or afterburner connected directly to the gas discharge of the kiln. This refractory lined chamber is equipped with auxiliary burners and air injection systems to ensure combustion occurs at the appropriate temperature. The afterburner generally operates with 120-200% excess air at a temperature of 1100-1450°C and a gas residence time of up to 3 seconds.

Process variations

Recently a variation on the standard kiln has become available. The European Von Roll organization produces a "rocking" kiln which is essentially the same as a rotary kiln but discharges ash and residues in batches. As its name implies, this kiln, which resembles in most ways a standard kiln, normally rotates only 45° from centre in each direction, rather than the conventional 360° rotation. The operating temperature of the kiln is in the range of 600-1300°C.

The bottom ash is discharged on a batch basis by rotating the kiln 120-180° and using the flue gas exit, which is normally at the top of the kiln, as the ash outlet. The ash is water quenched. By keeping the ash in the combustion chamber for a fixed period of time, the residual carbon in the ash is minimized.

Applicability and efficiency

- Capable of thermally destroying a wide variety of organic wastes.
- Capable of achieving a thorough burnout for a wide variety of solids (granular, irregular and unprepared large bulky materials), high organic aqueous wastes, organic liquids, organic sludges and gaseous wastes which can be fed independently or in combination.
- Consistently achieves 99.99% to 99.9999% destruction and removal efficiencies (DRE) with good volume reduction and burnout.

Advantages

- Adaptable to various feed mechanism designs and permits continuous ash removal.
- Can destroy toxic compounds that are difficult to thermally degrade.
- Can incinerate a wide variety of hazardous wastes (liquids, solids, sludges).
- Waste can be fed to the kiln without preheating or mixing.
- Rotational speed of the kiln allows a turndown ratio (maximum to minimum operating range) of about 50%.

Limitations

- Heat release rates are usually limited to 931,000 - 1,300,000 kJ/hr.m^3 (20,000 - 40,000 BTU/hr.ft^3).
- The feed rates are typically in the range of 2,000 lb/hr to 12,000 lb/hr for solids and 200 L/hr to 1,100 L/hr for liquids.

Cost evaluation

The capital cost for a treatment capacity of 40,400 tonnes/year is estimated at $44,564,000, based on a detailed study (2) done in 1985 and indexed to 1994 Canadian dollars. The operating costs, including materials ($231,000), electricity ($198,000), fuel ($1,035,000), labour ($169,000), maintenance ($2,228,000) and other ($2,228,000) can be translated to approximately $150/tonne of waste treated (various aqueous solutions). Steam generated from the process could be recovered (estimated at 12.0 GJ/tonne) and would have a credit value of approximately $81/tonne of waste.

Approval requirements

A rotary kiln incinerator will generated an estimated 14 tonnes/tonne of air emissions (with traces of organics and inorganics), 50 kg/tonne of bottom ash and 85 kg/tonne of fly ash from the gas scrubber (2).

References

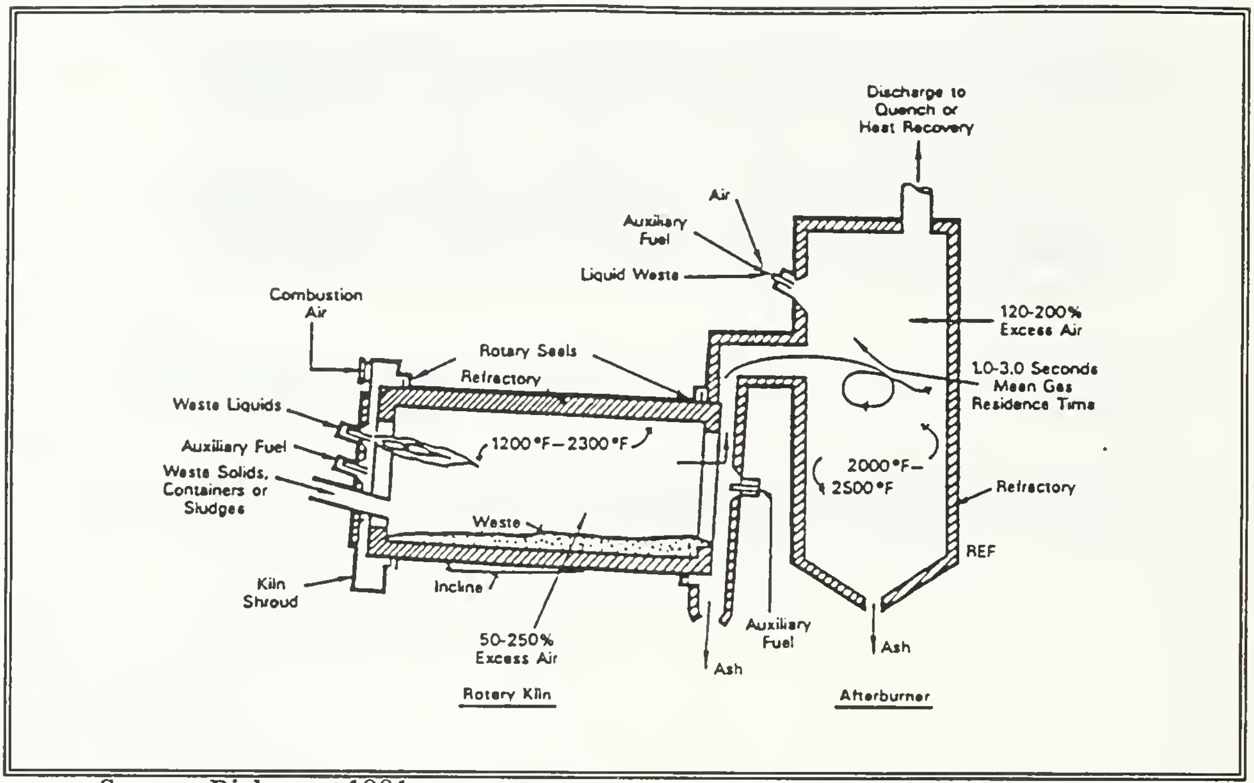
1. A.D. Little, 1986. Technologies and systems for treatment and disposal of special wastes in Ontario. Final report to Ontario Waste Management Corporation, by Arthur D. Little of Canada Limited, October 2, 1986.

2. A.D. Little, 1985. Systems and technologies for treatment and disposal of special wastes in Ontario. Draft report to Ontario Waste Management Corporation, by Arthur D. Little of Canada Limited, February 8, 1985 (unpublished).

3. Rickman, W.S., 1991. Handbook of incineration of hazardous wastes. CRC Press Inc., 1991.

4. Freeman, H.M., 1989. Standard Handbook of Hazardous Waste Treatment and Disposal, McGraw-Hill, ISBN 0-07-022042-5.

Figure 3.1a: typical rotary kiln and afterburner.



Source: Rickman, 1991.

3.2 FIXED HEARTH INCINERATION

Process summary

Wastes are incinerated in a fixed reactor chamber (unlike the rotary kiln) and gases are further burned in a secondary chamber.

Treatment process

Controlled-air incinerators employ a two-stage process similar to the rotary kiln with both a primary chamber and a secondary chamber (see Figure 3.2a). The primary chamber is usually operated in a sub-stoichiometric mode, typically 50-80% of theoretical combustion air requirements. The organic waste is thermally decomposed to yield a gaseous stream having a high heating value. This exhaust, rich in organics, is then directed to a secondary chamber where combustion is completed under excess air (100 to 200% excess air) and high temperature conditions.

Primary chamber operating temperature is typically in the range of 540-680°C while the secondary chamber is usually maintained at 870-1000°C. Secondary chambers should be designed to ensure thorough mixing of the gases with secondary air and to provide a gas residence time in the range of 0.5 to 2 seconds. Since air injection velocities to the primary chamber are controlled and sufficient time for destruction of particles is provided in the secondary chamber, these units typically produce low particulate emission levels.

Applicability and efficiency

- Used successfully to destroy gaseous wastes and solid wastes including pathological or biomedical wastes.
- Suitable for various solids, including irregular and bulky materials, low melting point material such as tars.

Advantages

- Simpler in design and operation than the rotary kiln or the fluidized bed.

Limitations

- Limited in size due to physical limitations in ram-feeding and transporting large amount of waste through the combustion chamber.

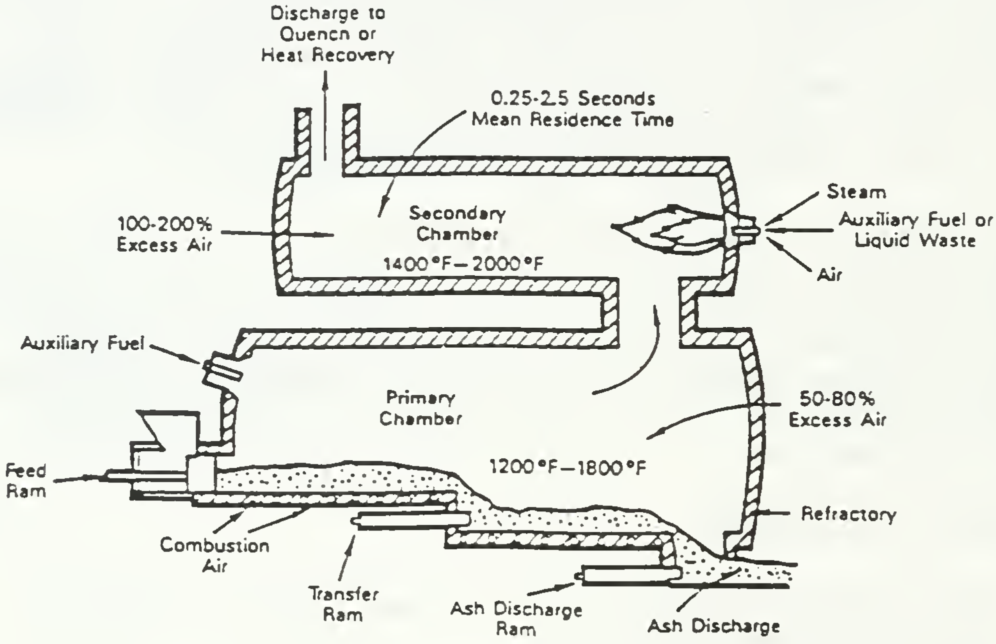
Approval requirements

Emissions are similar to the ones from the rotary kiln.

References

1. Rickman, W.S., 1991. Handbook of incineration of hazardous wastes. CRC Press Inc., 1991.

Figure 3.2a: Typical fixed hearth incinerator



Source: Rickman, 1991.

3.3 LIQUID INJECTION INCINERATION

Process summary

Liquid wastes are pre-filtered, atomized and injected into a combustion chamber for incineration.

Treatment process

A liquid injection incinerator consists of a horizontally or vertically oriented refractory-lined steel combustion chamber equipped with a nozzle or other device which atomizes the waste and mixes it with air into a suspension. The liquid waste can be atomized mechanically using a rotary cup burner or pressure injection, or with a two-fluid nozzle that makes use of high pressure air or steam.

Retention times are generally in the range of 0.5 to 2 seconds. Typical heat release rates for lean wastes (those requiring auxiliary fuel) are in the order of 931,200 $kJ/h.m^3$ (25,000 $BTU/hr.ft^3$). Rich wastes, which are do not require auxiliary fuel, are usually injected into high intensity burners such as the vortex burner where heat release rates as high as 3,725,000 $kJ/h.m^3$ (100,000 $BTU/hr.ft^3$) can be achieved.

Applicability and efficiency

- Can be used to dispose of almost any combustible liquid waste including lube oils, latex paints, solvents and pesticides.
- Can also be used to dispose of organic gases.

Advantages

- Operating temperatures have a wide range (650-1650°C); however, a typical temperature is 1000°C.

Limitations

- Suitable only for wastes that can be atomized; therefore, materials having a high viscosity pose special feeding or combustion problems and, generally, are unacceptable.

Cost evaluation

The capital cost for a treatment capacity of 5,300 tonnes/year is estimated at \$4,216,000, based on a detailed study (2) done in 1985 and indexed to 1994 Canadian dollars. The operating costs, including materials (\$36,600), electricity (\$48,900), fuel

($61,100), labour ($42,200), maintenance ($210,800) and other ($210,800) can be translated to approximately $115/tonne of waste treated (various aqueous solutions). Steam generated from the process could be recovered (estimated at 13.2 GJ/tonne) and would have a credit value of approximately $95/tonne.

Approval requirements

Liquid injection incinerator will generate an estimated 10 tonne/tonne of air emission (with traces of organics and inorganics), 200 kg/tonne of sludge (from pre-filtration), and 50 kg/tonne of fly ash from scrubbers.

References

1. A.D. Little, 1986. Technologies and systems for treatment and disposal of special wastes in Ontario. Final report to Ontario Waste Management Corporation, by Arthur D. Little of Canada Limited, October 2, 1986.

2. A.D. Little, 1985. Systems and technologies for treatment and disposal of special wastes in Ontario. Draft report to Ontario Waste Management Corporation, by Arthur D. Little of Canada Limited, February 8, 1985 (unpublished).

3. Rickman, W.S., 1991. Handbook of incineration of hazardous wastes. CRC Press Inc., 1991.

4. Freeman, H.M., 1989. Standard Handbook of Hazardous Waste Treatment and Disposal, McGraw-Hill, ISBN 0-07-022042-5.

3.4 FLUIDIZED BED INCINERATION

Process summary

A bed of granular material is made fluid by injecting air at the bottom of the reactor. Incineration is caused by heating the fluidized bed to about 800 °C. Various types of waste are inserted in the reactor and come in contact with the heated fluidized bed.

Treatment process

The fluidized bed incinerator usually consists of a vertical, refractory lined steel vessel containing a bed of granular material such as silica sand, limestone, alumina, or ceramic material (see Figure 3.4b). Air, which is blown through diffusers located below the bed material and separated by a refractory lined grid, expands the bed by 80-100% causing it to become fluidized. The fluidized bed reactor has an inside diameter ranging from 3 m (metres) to 15 m and a height of 10 m to 15 m. The bed is typically expanded to a depth of 2 metres leaving a freeboard of about 8 m 13 m. Wastes can be injected into the bed pneumatically or mechanically or can be gravity fed.

The constant moving action of the fluidized bed causes quick uniform mixing of wastes and bed material, resulting in good combustion conditions and relatively high heat transfer rates. The bed material functions as a heat sink capable of absorbing large amounts of heat generated during the combustion process. In typical fluidized bed systems, bed temperatures are maintained in the range of 760-870 °C (1400-1600 °F) by auxiliary burners located either above or below the bed. Gas velocities in the bed range from 5 to 7 ft/sec (1.5 to 2.1 m/sec).

Temperatures in the freeboard can be maintained at 1000 to 1400 °C (1800 to 2500 °F) with the use of auxiliary burners.

Modified process

Circulating fluidized bed combustion (CFBC) is a modified version of the fluidized bed incinerator (see Figure 3.4a). The CFBC process uses high velocity air to mix circulating solids in a highly turbulent combustion loop. The technology was initially developed in Germany and Finland during the 1960s, for efficient production of energy from biomass and low-rank coals. Since then, this technology has been adapted for incineration of a variety of organic wastes and residues.

Applicability and efficiency

- Used for many years in a number of different industries for various purposes.
- Quite versatile, capable of destroying a wide range of solid, liquid and gaseous wastes including sewage sludge, petroleum waste and wastes from the paper industry.

Advantages

- Can tolerate large fluctuations in feed rate and composition because of the high amount of heat stored in the bed, typically in the order of 596,000 kJ/m^3 (16,000 BTU/ft^3).
- Tend to minimize the formation of nitrogen oxides since it can operate satisfactorily with relatively low gas temperatures and excess air requirements.

Limitations

- Difficult to remove residual materials from the bed.

Cost evaluation

The capital cost for a treatment capacity of 38,000 tonnes/year is estimated at $37,723,000, based on a detailed study (2) done in 1985 and indexed to 1994 Canadian dollars. The operating costs, including materials ($216,300), electricity ($185,900), fuel ($418,300), labour ($168,600), maintenance ($1,886,000) and other ($1,886,000), can be translated to approximately $125/tonne of waste treated (various aqueous solutions). Steam generated from the process could be recovered (estimated at 9.6 GJ/tonne) and would have a credit value of approximately $69/tonne.

Approval requirements

Fluidized bed incineration will generate an estimated 14 tonne /tonne of air emissions (with trace amounts of organics and inorganics), 85 kg/tonne fly ash from scrubbers, 150 kg/tonne of bottom ash.

References

1. A.D. Little, 1986. Technologies and systems for treatment and disposal of special wastes in Ontario. Final report to Ontario Waste Management Corporation, by Arthur D. Little of Canada Limited, October 2, 1986.

2. A.D. Little, 1985. Systems and technologies for treatment and disposal of special wastes in Ontario. Draft report to Ontario Waste Management Corporation, by Arthur D. Little of Canada Limited, February 8, 1985 (unpublished).

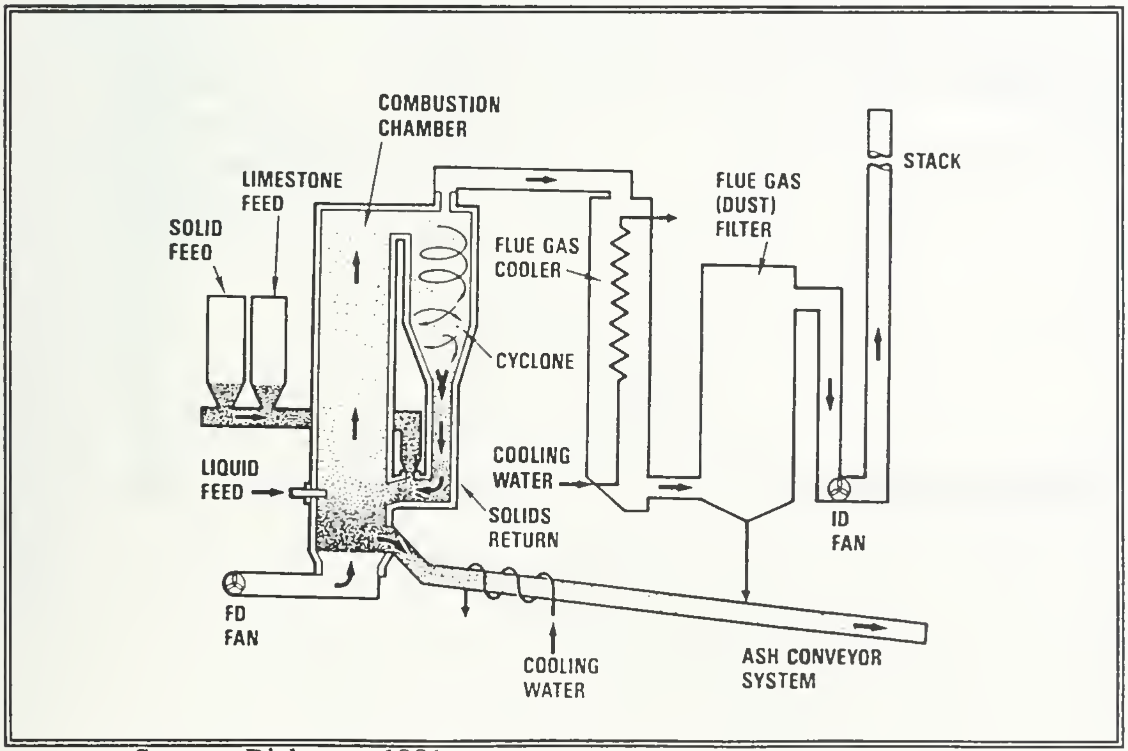
3. Desai, D.L., P.L. Mourot, S.A. Sterling and E.J. Anthony, 1994. Experimental investigation of CFBC technology for the decontamination of highly chlorinated PCB wastes. Canada Centre for Mineral and Energy Technology (CANMET), Energy Research Laboratories, Ottawa, Division report ERL 94-01(TR). January 1994.

4. Coulthard, E.J., J.Korenberg and K.D. Oswald, 1991. Co-firing coal and hospital waste in a circulating fluidized bed boiler. Vol. 1, ASME 1991, pp. 537-546. Presented at the 1991 International Conference on fluidized bed combustion, Montreal, April 21-24, 1991.

5. Rickman, W.S., 1991. Handbook of incineration of hazardous wastes. CRC Press Inc., 1991.

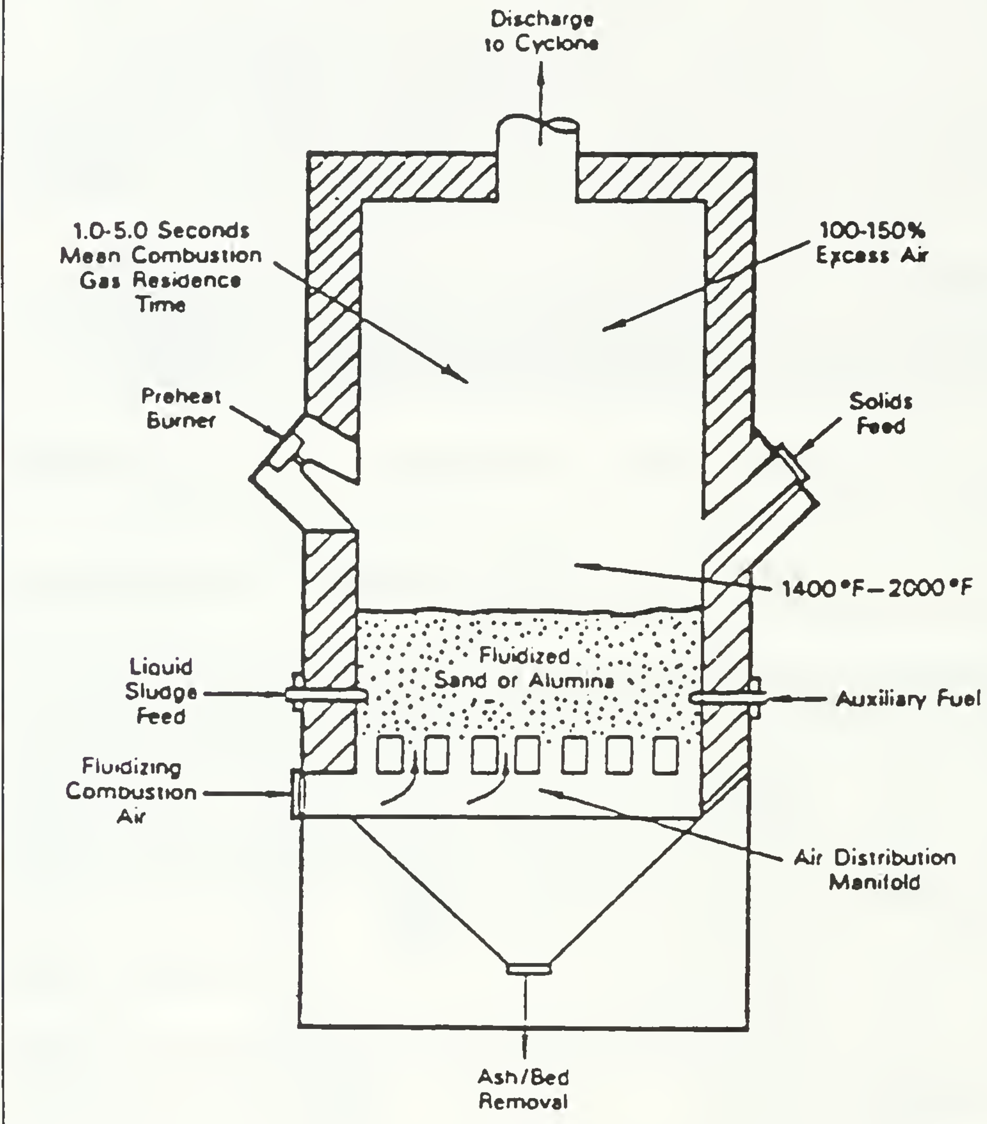
6. Freeman, H.M., 1989. Standard Handbook of Hazardous Waste Treatment and Disposal, McGraw-Hill, ISBN 0-07-022042-5.

Figure 3.4a: Circulating fluidized bed combustor (CFBC)



Source: Rickman, 1991.

Figure 3.4b:Typical fluidized bed incinerator


Discharge to Cyclone
1.0-5.0 Seconds Mean Combustion Gas Residence Time
100-150% Excess Air
Preheat Burner
Solids Feed
1400°F–2000°F
Liquid Sludge Feed
Fluidized Sand or Alumina
Auxiliary Fuel
Fluidizing Combustion Air
Air Distribution Manifold
Ash/Bed Removal

Source: Rickman, 1991.

4. CHEMICAL TREATMENT PROCESSES

4.1 ALKALI METAL DECHLORINATION

Process Description

These processes displace chlorine from organic compounds in liquids by adding an alkali metal. The end result is generally a chloride salt and a sludge.

Applicability and efficiency

- The process is used to treat liquid PCBs, other chlorinated hydrocarbons, acids, thiols, and dioxins.
- PCBs in liquid can be reduced to less than 2 ppm.

Advantages

- Very efficient.
- Mobile processing possible.

Limitations

- Reagent must be handled with care to prevent fires or explosions.
- The sludge and salt which is produced in the process must be separated from the remaining oil and disposed.
- The liquids should be dewatered before treatment since water reacts with the reagent and deactivates it.
- Generally limited to a maximum PCB concentration of 1%.

4.2 ALKALINE CHLORINATION

Process Description

In this reaction, chlorine is added to the contaminated liquid which has been or is a basic solution. The chlorine then chemically oxidizes the contaminant.

Applicability and efficiency

- Used to treat free cyanides and complex cyanides (aqueous salts).
- Very efficient.

Advantages

- Completely detoxifies the waste when the process is properly operated.

Limitations

- pH must be controlled closely (between 7.5 and 9.0) to prevent formation and release of toxic hydrogen cyanide gas.
- Reagent can react with other compounds in solution.
- Elimination of chlorine usage is receiving increased pressure from environmental groups.

4.3 CATALYTIC DEHYDROCHLORINATION

Process Description

The chemical reaction is based on the combination of hydrogen with the contaminant. The reaction is enhanced by metals which are the base on which the reaction occurs but are not changed during the reaction. Coating of a catalyst's surface can reduce the catalyst's effectiveness.

Applicability and efficiency

- Used to dechlorinate polychlorinated hydrocarbons including PCBs with high pressure hydrogen gas in the presence of a catalyst.

Advantages

- Does not produce dioxins or furans.

Limitations

- This is still a laboratory scale treatment technology.
- Catalysts are quickly deactivated by impurities such as tars or sulphur compounds.
- Costly process.
- Catalysts are often hazardous chemicals.

4.4 CHEMICAL OXIDATION

Process summary

Negatively charged ions such as oxygen or chlorine are reacted with the contaminant so that a less toxic chemical is produced.

Process principle

Oxidation occurs when one or several electrons are removed from an ion or a molecule. Reduction occurs when electron(s) are added to a substance. For example Zn^0 can be converted or oxidized to the metal ion Zn^{2+} by loosing 2 electrons. In turn, Zn^{2+} can be reduced to Zn^0 by taking 2 electrons. Oxidation-reduction, or redox, reactions have an important role in treatment of wastes, as they facilitate the decomposition and re-attachment of certain elements to other molecules.

A variation of this process is wet air oxidation where the oxidation occurs at elevated temperatures in a pressurized vessel.

Chemical oxidation process

The process generally involve the mixing of two liquids (the waste and the oxidation reagents), or the contacting of an aqueous solution with a gas. Either batch or continuous processing can be used.

Some reactions are rapid (in the order of 1-2 seconds, such as oxidation of sodium bisulphite by sodium hypochlorite). Mixing of the reactants for such reactions is done in a continuous reaction pipeline where the reaction is monitored by temperature rise and redox potential.

Oxidation of some organics may require several hours at high temperature. Batch reactors are normally used in this case, where pressurized vessels may be required for temperatures above 100 °C.

Applicability and Efficiency

- Used to treat a wide variety of wastes including leachate, non-halogenated spent solvents, halogenated organics, oily waste, fuel wastes and other organic wastes.
- More suited for wastes with low organic content.
- Solids must be in solution to be effectively treated.

Advantages

- Applicable to a wide variety of wastes.
- A conventional process.

Limitations

- Reactions can be explosive.
- Waste composition must be well known to prevent the inadvertent production of a more toxic or more hazardous end product.

Cost evaluation

The capital cost for a treatment capacity of 3,500 tonnes/year is estimated at $407,000, based on a detailed study (3) done in 1985 and indexed to 1994 Canadian dollars. The operating costs, including materials ($46,000), electricity ($21,700), labour ($42,200), maintenance ($20,400) and other ($20,400), can be translated to approximately $42/tonne of waste treated (various aqueous solutions or sludges containing cyanides, sulphides and reactive anions).

Approval requirement

An estimated 50 kg/tonne of sludge will be generated from chemical oxidation. An estimated 1.5 tonne/tonne of aqueous stream will be also generated with less than 3 ppm cyanide sulphides (3).

Reference

1. Freeman, H.M., 1989. Standard Handbook of Hazardous Waste Treatment and Disposal, McGraw-Hill, ISBN 0-07-022042-5.

2. A.D. Little, 1986. Technologies and systems for treatment and disposal of special wastes in Ontario. Final report to Ontario Waste Management Corporation, by Arthur D. Little of Canada Limited, October 2, 1986.

3. A.D. Little, 1985. Systems and technologies for treatment and disposal of special wastes in Ontario. Draft report to Ontario Waste Management Corporation, by Arthur D. Little of Canada Limited, February 8, 1985 (unpublished).

4.5 CHEMICAL PRECIPITATION

Process summary

In chemical precipitation, a soluble substance is converted to an insoluble form by a chemical reaction or by reducing the solubility of the substance in the solution. The insoluble material chemically reacts to produce a solid which can then be removed by physical treatment methods.

Process principle

Several chemicals have been shown to be effective in removing heavy metals from aqueous wastes. Calcium hydroxide (lime) is the most widely used method. Most metals can also be precipitated as sulphides, and certain metals as carbonates.

Hydroxide precipitation

Calcium hydroxide (lime) or sodium hydroxide (caustic) are used as precipitants to remove metals as insoluble metal hydroxides. The generic chemical reaction is as follows:

$$\mathrm{METAL}^{++} + \mathrm{Ca(OH)_2} \dashrightarrow \mathrm{METAL(OH)_2} + \mathrm{Ca}^{++}$$

or

$$\mathrm{METAL}^{++} + \mathrm{Na(OH)_2} \dashrightarrow \mathrm{METAL(OH)_2} + \mathrm{Na}^{++}$$

The residual effluent concentrations (reaching less than 1.0 mg/L and sometime as low as 0.1 mg/L) is dependant on a number of factors:

- reaction conditions, especially pH;
- metals present;
- precipitant used.

The solubility of several metal hydroxides are amphoteric, i.e. they are increasingly soluble at both low and high pH, with a pH point of minimum solubility (see Figure 4.5a). In most cases a pH between 9 and 11 produces acceptable effluent results. For a waste containing several metals, several precipitation stages (with different pH) may be required to remove all metals of concern to acceptable levels.

Sulphide precipitation

Sulphide precipitation involves the reaction of metal ions with a sulphide radical:

$$\mathrm{METAL}^{++} + \mathrm{FeS} \dashrightarrow \mathrm{METAL\text{-}S} + \mathrm{Fe}^{++}$$

Several sources of sulphides can be used, including sodium sulphide (Na_2S), sodium hydrosulphide ($NaHS$) which are soluble, and ferrous sulphide (FeS) which is slightly soluble.

Sulphide precipitation has some advantages over hydroxide precipitation:

- solubilities are lower than those of metal hydroxides (see Fig. 4.5b);
- metal sulphides are not amphotheric.

There are some drawbacks however:

- potential of generating hydrogen sulphide gas (which can be reduced by maintaining a pH above 8, and controlling and monitoring the level of hydrogen sulphide).
- potential for release of excessive sulphide in the effluent (which can be controlled.

Carbonate precipitation

For certain metals (i.e. cadmium and lead), carbonate precipitation can produce effluent concentration as good as the ones from hydroxide precipitation, with the advantage of a lower operating pH (8 compared to above 10) and denser and more filterable sludge. The generic reaction of sodium carbonate (soda ash) and divalent metal is as follows:

$$\text{METAL}^{++} + Na_2CO_3 \text{ --> } \text{METAL-}CO_3 + 2Na^+$$

The process is not effective for all metals (i.e. zinc and nickel).

Sodium borohydride precipitation

Sodium horohydride is a reducing agent that can precipitate certain metals in solution as insoluble elemental metals (e.g. lead, mercury, nickel, copper, cadmium, sold, silver and platinum). Simplified reactions are as follows:

$$4\text{METAL}^{++} + NaBH_4 + 2H_2O \text{ --> } NaBO_2 + 4\text{METAL} + 8H^+$$

$$4\text{METAL}^{++} + NaBH_4 + 8OH^- \text{ --> } NaBO_2 + 4\text{METAL} + 6H_2O$$

Applicability and efficiency

- Wide application in the removal of toxic metals from aqueous wastes.

Advantages

- A conventional, commercially available process.

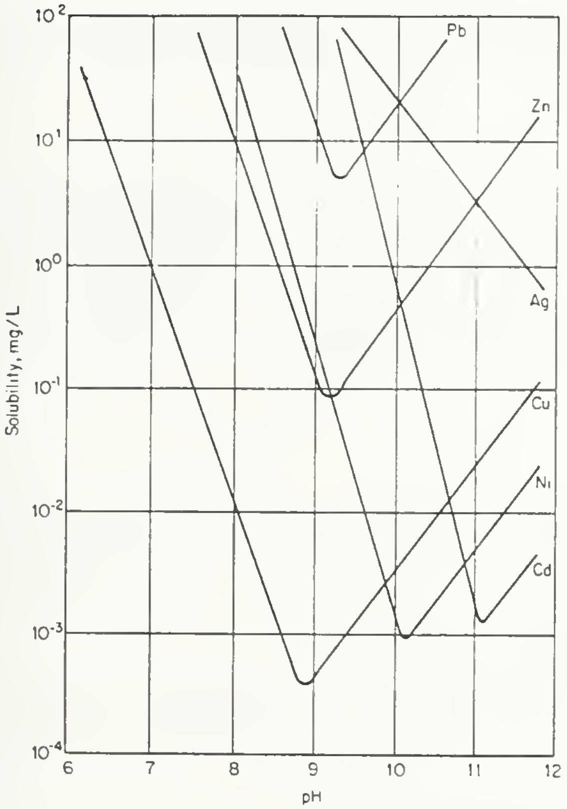
Limitations

- Not all metals have a common optimum pH at which they precipitate.
- Chelating and complexing agents can interfere with the process.
- Organics are not removed.

Reference

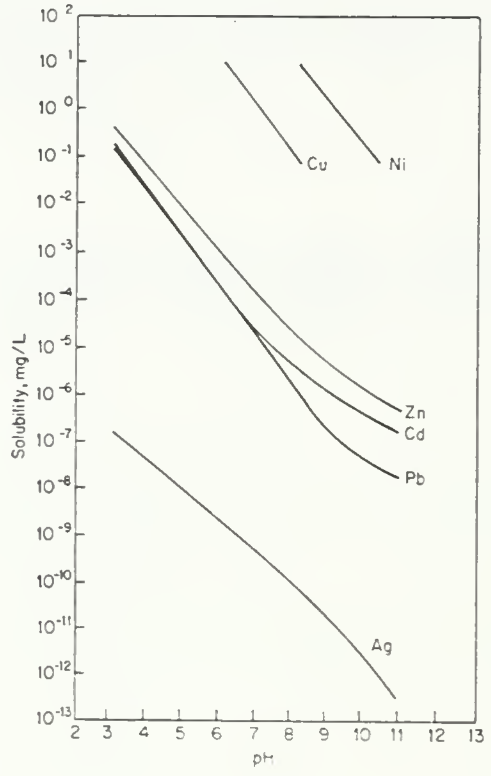
1. Freeman, H.M., 1989. Standard Handbook of Hazardous Waste Treatment and Disposal, McGraw-Hill, ISBN 0-07-022042-5.

FIGURE 4.5a: Solubility of metal hydroxides.



Source: Freeman, 1989.

FIGURE 4.5b: Solubility of metal sulfides.



Source: Freeman, 1989.

4.6 CHEMICAL REDUCTION

Process Description

Positively charged ions (e.g. hydrogen, sulphur dioxide, iron and sodium) are reacted with the contaminant so that a less toxic chemical is produced.

Process principle

Reduction occurs when electron(s) are added to a substance. Oxidation occurs when one or several electrons are removed from an ion or a molecule. For example, Zn^{2+} can be reduced to Zn^0 by taking 2 electrons. In turn, Zn^0 can be converted or oxidized to the metal ion Zn^{2+} by loosing 2 electrons. Reduction-oxidation (or redox), reactions have an important role in treatment of wastes, as they facilitate the decomposition and re-attachment of certain elements to other molecules.

Reduction process

The process generally involve the mixing of two liquids (the waste and the reduction reagents), or the contacting of an aqueous solution with a gas. Either batch or continuous processing can be used.

Some reactions are rapid (in the order of 1-2 seconds). Mixing of the reactants for such reactions is done in a continuous reaction pipeline where the reaction is monitored by temperature rise and redox potential.

Reduction of some organics may require several hours at high temperature. Batch reactors are normally used in this case, where pressurized vessels may be required for temperatures above 100 °C.

Applicability and efficiency

- Used to treat a wide variety of wastes including leachate, non-halogenated spent solvents, halogenated organics, PCB oily waste, fuel wastes and other organic wastes.
- Solids must be in solution to be effectively treated.

Advantages

- Applicable to a wide variety of wastes.
- Conventional process.

Limitations

- Reactions can be explosive.
- Waste composition must be well known to prevent the inadvertent production of a more toxic or more hazardous end product.

Cost evaluation

The capital cost for a treatment capacity of 3,500 tonnes/year is estimated at $407,000, based on a detailed study (3) done in 1985 and indexed to 1994 Canadian dollars. The operating costs, including materials ($46,000), electricity ($21,700), labour ($42,200), maintenance ($20,400) and other ($20,400), can be translated to approximately $42/tonne of waste treated (various aqueous solutions or sludges containing hexavelant chromium or other metals).

Approval requirement

An estimated 50 kg/tonne of sludge will be generated from chemical reduction (3).

Reference

1. Freeman, H.M., 1989. Standard Handbook of Hazardous Waste Treatment and Disposal, McGraw-Hill, ISBN 0-07-022042-5.

2. A.D. Little, 1986. Technologies and systems for treatment and disposal of special wastes in Ontario. Final report to Ontario Waste Management Corporation, by Arthur D. Little of Canada Limited, October 2, 1986.

3. A.D. Little, 1985. Systems and technologies for treatment and disposal of special wastes in Ontario. Draft report to Ontario Waste Management Corporation, by Arthur D. Little of Canada Limited, February 8, 1985 (unpublished).

4.7 HYDROLYSIS

Process summary

Various chemicals react actively or violently with water, producing either heat, gas, or pH variations in the solution. The use of water to destroy, decompose or alter the chemistry of certain wastes is considered hydrolysis.

Process principle

Use of hydrolysis technology in hazardous waste treatment is based on the fact that water can react and modify certain reactive chemicals. Under controlled conditions, the reactivity of the waste is reduced to hydrolysis products (some of them still toxic and hazardous) that need further treatment or management. The following Table 4.7a gives some examples of wastes suitable for hydrolysis treatment.

Table 4.7a: Reactive chemicals suitable for hydrolysis.

CHEMICALS GROUP (example)	HYDROLYSIS REACTION	HYDROLYSIS PRODUCTS
Metal alkoxides (sodium methoxide)	$NaOCH_3 + H_2O$ -> $NaOH + CH_3OH$ + heat	Corrosive sodium hydroxide; Toxic/flammable methanol; Exothermic reaction
Metal amides (lithium amide)	$LiNH_2 + H_2O$ -> $LiOH + NH_3$ + heat/fire	Corrosive solution Ammonia gas: irritant Exothermic/fire reaction
Carbides (calcium carbide)	$CaC_2 + 2H_2O$ -> $Ca(OH)_2 + C_2H_2$	Alkaline solution Acetylene gas: flammable and explosive air mixture
Cyanates (methylisocyanate)	$CH_3NCO + 2H_2O$ -> $CH_3NH_2 + H_2CO_3$	Highly toxic compound reduced to alkaline solution
Halines (aluminum trichloride)	$AlCl_3 + 3H_2O$ -> $Al(OH)_3 + 3HCl$	Hydrochloric acid solution: corrosive and toxic
Hydrides (lithium aluminum hydride)	$LiAlH_4 + 4H_2O$ -> $LiOH + Al(OH)_3 + 4H_2$	Corrosive solution. Hydrogen gas: explosive air mixture. Flame and explosion reaction.
Oxyhalides (phosphorus oxybromide)	$POBr_3 + 3H_2O$ -> $H_3PO_4 + 3HBr$ + heat	Corrosive hydrobromic acid.Toxic hydrogen bromide. Exothermic reaction.
Alkali metals (potassium)	$2K + 2H_2O$ -> $2KOH + H_2$	Corrosive potassium hydroxide. Explosive hydrogen gas. Flame and explosion reaction.

Silanes (trichloromethylsilanes)	$CH_3Cl_3Si + 3H_2O$ -> $CH_3Si(OH)_3 + 3HCl$	Hydrogen chloride produces corrosive and toxic solution.
Suffides (phosphorus pentasulfide)	$P_2S_5 + 5H_2O$ -> $P_2O_5 + 5H_2S$ + heat	Toxic hydrogen sulphide gas. Reaction exothermic.

Process design

The major factors to consider in the design is the explosive nature of the reactions and the production of toxic gases and corrosive residual solution. A typical design is illustrated in Figure 4.7a. A reaction tank is filled with alkaline (pH above 10.5) solution, which is circulated through the hammer mill. The reactive waste is introduced into the hammer mill by a conveyor and hopper. Adjustment of the pH solution is required during the treatment.

Reactive wastes (usually small volumes of solids and liquid in glass bottles, cans or plastic bags) are fed manually to the conveyor. As the containers are shredded in the hammer mill, the waste reacts with the circulating solution. Materials shredded to less than 12 mm fall in the reaction tank where the hydrolysis reaction is completed. Any gas produced in the hammer mill and the reaction tank is treated in a scrubber designed to remove particulates and to neutralize acid mists or ammonia gases.

When the solution in the tank becomes saturated, the aqueous portion is filtered off and sent to wastewater treatment facility. The solids (glass and metal fragments and precipitated salts) are sent to a secure landfill.

Because of explosion potential and toxic gases emission, the treatment system is housed in a dedicated room, constructed of explosion proof material (steel reinforced concrete walls and floor) and maintained under negative pressure to reduce risk of personnel exposure of toxic gases.

Applicability and efficiency

- Any reactive hazardous wastes not suitable for landfilling.

Advantages

- Safe and controlled process for highly reactive wastes.

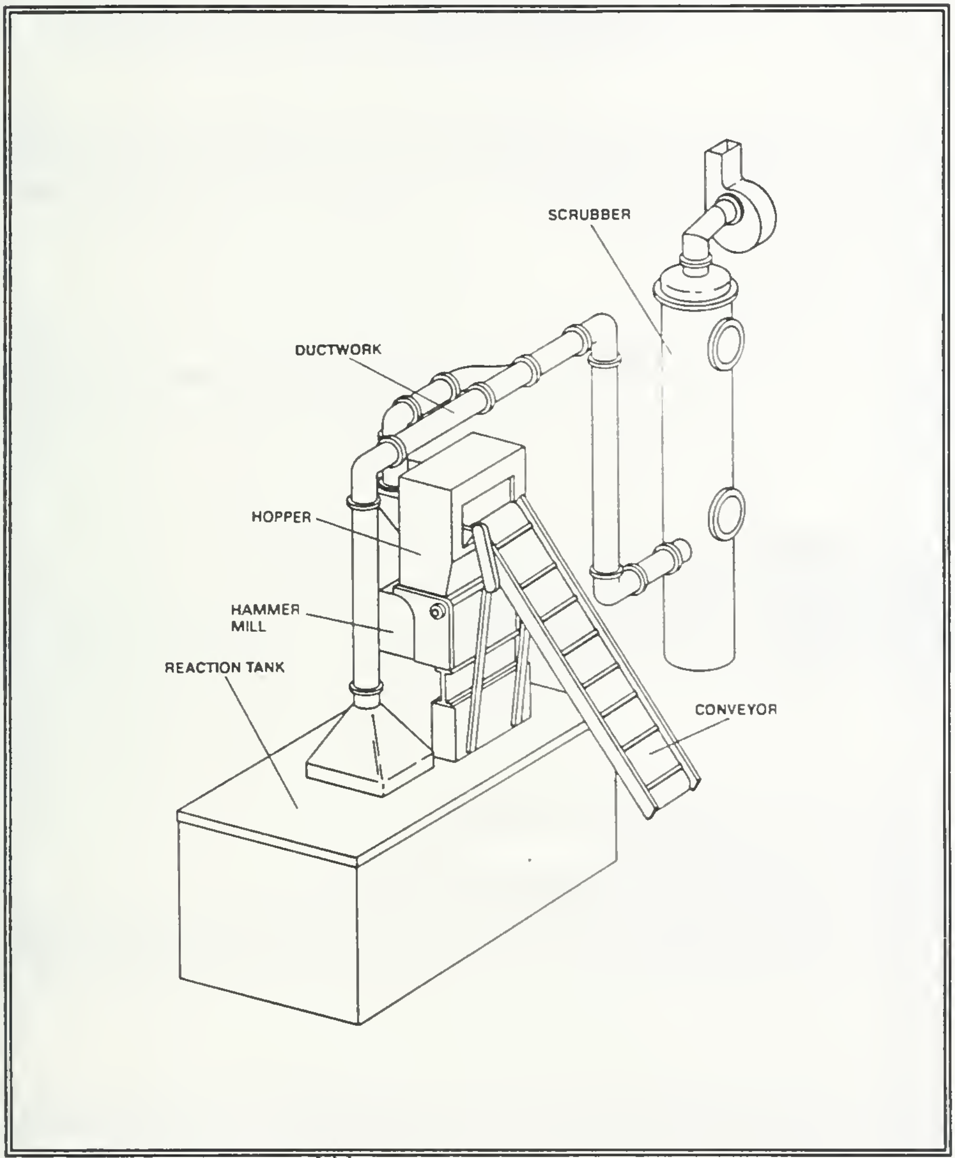
Limitations

- Costly process, specially for controlling the reactions.
- Acid hydrolysis applied to in-situ waste must be performed carefully because of the potential to mobilized any heavy metals present in the waste.

Reference

1. Freeman, H.M., 1989. Standard Handbook of Hazardous Waste Treatment and Disposal, McGraw-Hill, ISBN 0-07-022042-5.

FIGURE 4.7a: Typical design for hydrolysis traetment.



Source: Freeman, 1989.

4.8 ELECTROLYTIC OXIDATION

Process summary

An electrical current is passed through a solution resulting in oxidation of some chemicals. Some metals can be removed from the solution as they collect on the electrodes.

Process description

The electrolytic reactor consists of the electrodes, and a reactor tank. Recirculating pumps and a power supply provide the proper circulation of the solution and the transfer of metallic ions on the cathodes.

Applicability and efficiency

- Process is applicable to aqueous salts and particularly to cyanide bearing wastes.

Advantages

- Can treat high concentrations (up to 10%) of cyanide.
- Separates metals to allow their recovery.
- Initial investment and operating expenses are low.
- Equipment maintenance is minimal.

Limitations

- Solids must be dissolved prior to treatment.
- Process requires long time.
- Non-selective competition with other metal species.
- Not effective at recovering nickel, due to low reduction potential and high stability of Ni-CN complexes.

Cost evaluation

Electrolytic oxidation is more economic than ion exchange for low concentrations, generally below 10 mg/L. Ion exchange is more cost effective at concentrations between 100 and 1,000 mg/L.

Approval requirements

In electrolytic oxidation, gaseous products such as oxygen, hydrogen, or nitrogen may form at the anode, depending on the chemical composition of the solution.

Reference

1. Freeman, H.M., 1989. Standard Handbook of Hazardous Waste Treatment and Disposal, McGraw-Hill, ISBN 0-07-022042-5.

4.9 NEUTRALIZATION

Process summary

An acid waste is mixed with a alkaline (basic) waste to form a near neutral waste mixture. This action of neutralizing acids and bases generally form insoluble salts which can be removed from the waste mixture.

Process Description

In neutralization the pH of a material is adjusted by adding hydrogen ions [H^+] to an alkaline solution and hydroxyl ions [OH^-] to an acid solution until the pH reaches approximately 7. This is normally the first step in treating aqueous wastes that are outside of the normal pH range of 6-8.

The addition of appropriate quantities of the neutralizing agents is monitored and adjusted by pH measurement and control. In batch treatment, samples are taken regularly and pH measured and proper dose of acid/alkali added to the reactor. In a continuous flow system, automatic pH monitors check the acidity and control the feeding of the neutralizing agents (3).

Applicability and efficiency

- Applicable to a wide variety of wastes including acids, alkalis, aqueous salts, leachate, non-halogenated spent solvents, halogenated organics and other organic wastes.
- Typical neutralization chemicals are sulphuric acid, soda ash and lime slurry.

Advantages

- Common industrial process.
- Can treat both inorganic and organic wastes that are either excessively acidic or alkaline.

Limitations

- Must be performed in a well-mixed system to ensure completeness of the reaction.
- Care must be taken to ensure compatibility of the waste and treatment chemicals to prevent the formation of toxic or hazardous compounds.

Cost evaluation

Based on a detailed study (1) done in 1986 and indexed to 1994 Canadian dollars, the operating costs for a plant capacity of 21,000 tonnes/yr are evaluated at approximately $12/tonne of waste treated.

Approval requirements

There are no air releases from neutralization, provided that only appropriate wastes are treated. Adding acid to neutralize wastes containing cyanides or sulphides may cause the release of toxic hydrogen cyanide or hydrogen sulphide gases respectively.

References

1. A.D. Little, 1986. Technologies and systems for treatment and disposal of special wastes in Ontario. Final report to Ontario Waste Management Corporation, by Arthur D. Little of Canada Limited, October 2, 1986.

2. A.D. Little, 1985. Systems and technologies for treatment and disposal of special wastes in Ontario. Draft report to Ontario Waste Management Corporation, by Arthur D. Little of Canada Limited, February 8, 1985 (unpublished).

3. Proctor & Redfern Limited, 1982. Generic process technologies study. Prepared for OWMC Environmental Assessment, Volume C2. Revised December 1982.

5. BIOLOGICAL TREATMENT PROCESSES

5.1 ACTIVATED SLUDGE

Process summary

A mixture of wastewater and micro-organisms is agitated and aerated, causing the microorganisms to use the organics in the waste. The accumulation of microorganisms at the bottom of the reactor forms an active mass of microbes called "activated sludge".

Process description

Microorganisms that use oxygen, adsorb organics out of a waste stream and then use the organics as a food in their life cycle and release carbon dioxide. The microorganisms are removed from the treated waste stream and recycled back into the untreated influent. Excess microorganisms are further treated.

Applicability and efficiency

- Common biological wastewater treatment method used in numerous Ontario municipalities for treating domestic sewage, containing also industrial wastes.
- Used for leachate, non-halogenated solvents, halogenated organics, PCBs, oily waste, certain biomedical wastes, fuel wastes and other organics wastes.

Advantages

- Conventional, well developed process.
- Can be adapted to most organic wastes.

Limitations

- Requires consistent, stable operating conditions.
- Not suitable for removing highly chlorinated organics, aliphatics, amines or aromatic compounds.
- Some heavy metals and organics are harmful to the treatment organisms.
- Can result in the escape of volatile, hazardous materials.

Cost evaluation

The cost evaluation is based on a capacity plant of 1,500 tonne/yr. The capital cost is estimated at $45,000. The variable costs include materials ($7,600) and electricity

($2,400). The fixed costs include labour ($10,500), maintenance ($2,300) and other ($2,300). The operating cost is calculated at approximately $20/tonne (1).

Approval requirements

Typical discharges from the process include 130 kg/tonne of sludge and 1,700 kg/tonne of vent gases for incineration or scrubbing (1).

References

1. A.D. Little, 1985. Systems and technologies for treatment and disposal of special wastes in Ontario. Draft report to Ontario Waste Management Corporation, by Arthur D. Little of Canada Limited, February 8, 1985 (unpublished).

2. Proctor & Redfern Limited, 1982. Generic process technologies study. Prepared for OWMC Environmental Assessment, Volume C2. Revised December 1982.

3. Freeman, H.M., 1989. Standard Handbook of Hazardous Waste Treatment and Disposal, McGraw-Hill, ISBN 0-07-022042-5.

5.2 ANAEROBIC DIGESTION

Process summary

Microorganisms that live in the absence of oxygen absorb organics from a waste stream and then use the organics as a food source. The end products are methane gas and a sludge composed of microorganisms and residual contaminants.

Process description

Conventional high rate digestion uses two vessels, one for mixing the digesting sludge and the waste, one for separation (sedimentation) of the liquid from the microorganisms (see Figure 5.2a).

Various processes have been designed commercially to promote effective methods for maintaining microorganisms in the reactors and efficiently exposing the microorganisms to the organic wastes. These processes include:

- Fixed bed reactor (see section 5.3).
- Fluidized bed reactor (see section 5.4).
- Upflow anaerobic sludge blanket (UASB).

Upflow anaerobic sludge blanket (UASB)

The liquid waste enters evenly across at the bottom of the reactor and flows upwards through the sludge bed (see Figure 5.2b). The organic matter in the waste is consumed by the microbial population in the sludge bet and converted into biomass and gas.

Above the bed is the sludge blanket zone which provides an area for an ideal mixing between the organics in the leachate and the microorganisms.

Throughout the biological activity, gas production results in the formation of gas bubbles. As the gas bubbles rise through the sludge blanket, they provide gentle mixing (4).

Applicability and efficiency

- Used for aqueous wastes with low to moderate levels of organics such as leachate, non-halogenated solvents, halogenated organics, PCBs, oily waste, certain biomedical wastes, fuel wastes and other organic wastes.

- Common biological process used in many Ontario municipalities and in several industries to treat organic wastes (2).

Advantages

- Can handle certain halogenated organics better than aerobic treatment.
- Produces methane which can be used for heating the process and buildings.

Limitations

- Volatile, hazardous gases may be formed and escape unless controlled by off-gas burning.

Cost evaluation

The cost evaluation is based on a capacity plant of 1,500 tonne/yr. The capital cost is estimated at $45,000. The variable costs include materials ($7,700) and electricity ($1,200). The fixed costs include labour ($10,500), maintenance ($2,300) and other ($2,300). The operating cost is calculated at approximately $20/tonne (1).

Approval requirements

Typical discharges from the process include 12 kg/tonne of sludge and 30 kg/tonne of methane for recycling (1).

References

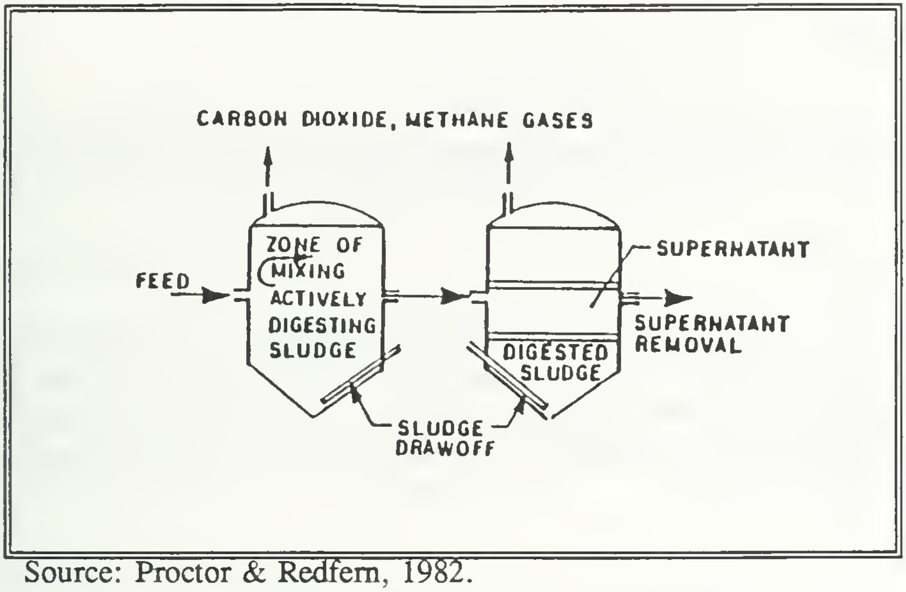
1. A.D. Little, 1985. Systems and technologies for treatment and disposal of special wastes in Ontario. Draft report to Ontario Waste Management Corporation, by Arthur D. Little of Canada Limited, February 8, 1985 (unpublished).

2. Proctor & Redfern Limited, 1982. Generic process technologies study. Prepared for OWMC Environmental Assessment, Volume C2. Revised December 1982.

3. Freeman, H.M., 1989. Standard Handbook of Hazardous Waste Treatment and Disposal, McGraw-Hill, ISBN 0-07-022042-5.

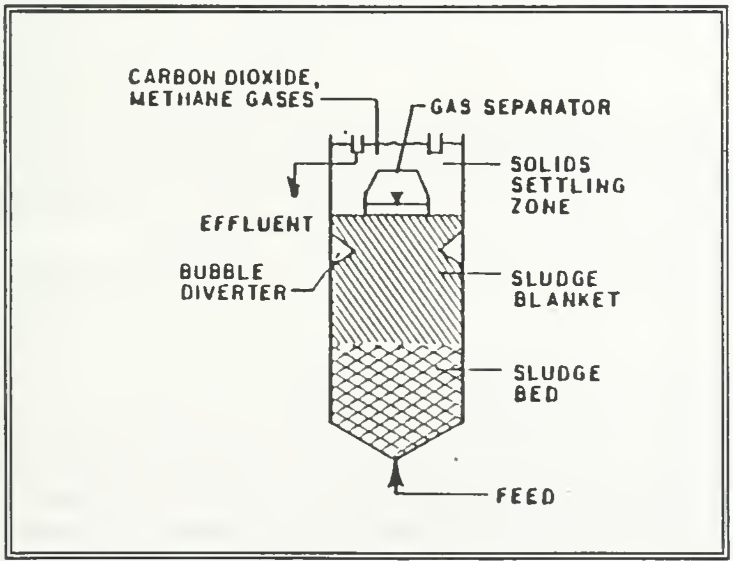
4. MOEE, 1995. Treatment technologies for landfill leachates. ISBN 0-7778-3731-5. PIBS 3332E. January 1995.

Figure 5.2a: Conventional high rate digester.



Source: Proctor & Redfern, 1982.

Figure 5.2b: Upflow Anaerobic Sludge Blanket (UASB)



Source: Proctor & Redfern, 1982.

5.3 FIXED BED REACTOR

Process summary

Fixed bed reactors are either anaerobic or aerobic processes where the microorganisms are attached to some support mechanism and the waste flow is passed over the bed of microorganisms.

Process description

A biological mass of microorganisms are initially grown on an inert, high-surface area material in the reactor cell. A waste stream is circulated along the vertical length of the reactor, making contact with the microorganisms. The process can be operated in an upflow or downflow direction, depending on the nature of the solids in the waste (solubility, concentration).

Applicability and efficiency

- Used for leachate, non-halogenated solvents, halogenated organics, PCBs, oily waste, certain biomedical wastes, fuel wastes and other organics wastes.
- COD (chemical oxygen demand) removal efficiencies of 80% to 95%, with high organic loading rates (10 - 20 kg/m^3.day).

Advantages

- Reactor is relatively stable to toxic and shock loading.
- Can be operated either in upflow or downflow direction (thus avoiding solids from entering reactor).

Limitations

- Start-up can be exceptionally long.

References

1. Freeman, H.M., 1989. Standard Handbook of Hazardous Waste Treatment and Disposal, McGraw-Hill, ISBN 0-07-022042-5.

2. Proctor & Redfern Limited, 1982. Generic process technologies study. Prepared for OWMC Environmental Assessment, Volume C2. Revised December 1982.

5.4 FLUIDIZED BED REACTOR

Process summary

Fluidized bed reactors mostly use aerobic microorganisms which are attached to a bed of material (sand or granular particles) that is kept in motion by either the upward flow of liquid waste or by a stream of air.

Process description

A closed vessel contains sand or similar granular particles covered with microorganisms. The liquid waste (wastewater) is introduced in an upward flow where the sand remain in suspension for contact of the biomass with the contaminants. Air may be introduced also to provide oxygen to the aerobic biological reaction and added fluidity of the bed.

Applicability and efficiency

- Used for leachate, non-halogenated solvents, halogenated organics, PCBs, oily waste, certain biomedical wastes, fuel wastes and other organics wastes.
- High efficiency (>90%) for organic loading rates above 15 kg/m^3.day.

Advantages

- Reactor is relatively stable to toxic and shock loading.

Limitations

- Cost of pumping power can be a significant part of the operating costs.

Cost evaluation

The cost evaluation is based on capacity of 1,500 tonne/yr of aqueous waste solution less than 10% organics residue. The capital cost is estimated at $58,000. The variable costs include materials ($7,600), and electricity ($2,300). Fixed costs include labour ($10,500) maintenance ($2,900) and other ($2,900). The operating cost is estimated at near $20/tonne of aqueous waste (1).

Approval requirement

The effluent is estimated at 130 kg/tonne of sludge for disposal or incineration. The aqueous stream (near 900 kg/tonne) may contain dissolved organics, salts and suspended solids.

References

1. A.D. Little, 1985. Systems and technologies for treatment and disposal of special wastes in Ontario. Draft report to Ontario Waste Management Corporation, by Arthur D. Little of Canada Limited, February 8, 1985 (unpublished).

2. Freeman, H.M., 1989. Standard Handbook of Hazardous Waste Treatment and Disposal, McGraw-Hill, ISBN 0-07-022042-5.

3. Proctor & Redfern Limited, 1982. Generic process technologies study. Prepared for OWMC Environmental Assessment, Volume C2. Revised December 1982.

5.5 LAND TREATMENT

Process summary

The use of land to treat organic waste relies on the microorganisms contained in the soil to convert the organic waste to carbon dioxide in an aerobic environment. Wastes can be spread on top of the soil or incorporated into the top surface of the site.

Process description

There are a number of ways to apply liquid wastes to the land (3). The method of application depends upon the soil, the type of crop, the climate and the topography. The three methods most commonly used are: spray irrigation, ridge and furrow irrigation, and overland flow irrigation.

In spray irrigation, the liquid waste is sprayed above the surface of the ground to fall like rain on the site. This method is the most commonly used and acceptable method.

In the ridge and furrow irrigation system, the ground is groomed into alternating ridges and furrows. The liquid waste is allowed to flow by gravity in the furrows and seep into the ground. The furrows must be allowed to dry out after each application of waste so that the soil pores do not become clogged.

In the overland flow irrigation, liquid wastes are applied across grass-covered, uniformly graded, gentle slopes of land with relatively impermeable soils.

Applicability and efficiency

- Used for leachate, non-halogenated solvents, halogenated organics, oily waste, fuel wastes and other organics wastes.
- Efficiency dependant on presence of the nutrient and the absence of toxins in the waste (for the microorganisms).
- Applicable in Southern Ontario regions for about 5 summer months per year.
- Used in majority by petroleum and chemical industries for treatment of specific waste streams (2).

Advantages

- Can be used in remote areas, over grassland or forested areas.
- Soil used as biological treatment and filtration.

Limitations

- Biological activities severely reduced at temperatures near or below freezing point.
- Non biodegradable residues (inorganics, solids) remain in the soil, untreated.
- Require large areas of land.
- Possible contamination of surface and ground water from runoffs.
- Potential odour and aerosol problems.

Cost evaluation

The cost evaluation is based on a capacity of 12,000 tonne/yr for various oily wastes. The price of land is the major capital cost in this process and has been estimated at $1.7 million in Southern Ontario. Variable costs include materials ($75,000), contract mobile equipment ($77,000) and contract labour ($132,500). Fixed costs include labour ($21,100), maintenance (($31,300) and other (($80,700). The operating cost is estimated at $35/tonne (1).

Approval requirement

The application of organic wastes and tilling of the waste/soil mixture will generate an estimated 250 kg/tonne (of waste) in volatile organic air emissions (1).

References

1. A.D. Little, 1985. Systems and technologies for treatment and disposal of special wastes in Ontario. Draft report to Ontario Waste Management Corporation, by Arthur D. Little of Canada Limited, February 8, 1985 (unpublished).

2. Freeman, H.M., 1989. Standard Handbook of Hazardous Waste Treatment and Disposal, McGraw-Hill, ISBN 0-07-022042-5.

3. MOEE, 1995. Treatment technologies for landfill leachates. ISBN 0-7778-3731-5. PIBS 3332E. January 1995.

5.6 WASTE STABILIZATION LAGOON

Process summary

Stabilization lagoons are ponds designed to treat liquid organic wastes by using either aerobic or anaerobic microorganisms.

Process description

Stabilization lagoon are usually large shallow basins or earth pits which have been excavated, and lined with impermeable materials to prevent seepage or migration of the liquid waste from the impoundment area. There are 3 types of lagoon designs: aerobic (with oxygen present), anaerobic (in the absence of oxygen) and facultative (combination of aerobic and anaerobic conditions) (1).

Aerobic lagoons

Aerobic lagoons are usually very shallow basins that are used for treatment of wastewater by the action of algae and bacteria. Aerobic conditions prevail throughout the entire lagoon. There are 2 types of aerobic designs: symbiotic aeration and surface aeration.

In the case of symbiotic aeration, aerobic conditions are maintained in the lagoon by algae growth. Oxygen is produced by algae through the action of photosynthesis and in turn consumed by the bacteria during the aerobic degradation of organic matter in the waste. There is a symbiotic relationship of algae and bacteria. The success of these aerobic ponds depend on the prolific growth of algae. These ponds are usually very shallow (15 to 45 cm deep).

In the case of surface aeration, air is artificially introduced into the liquid by means of mechanical surface aerators. In other similar designs, air is introduced at the bottom of the lagoon through perforated conduits or diffused aerators. These lagoons are usually deeper than the previous type (up to 3 m deep).

Anaerobic lagoons

In anaerobic lagoons, the decomposition or stabilization of organics takes place as a result of microbial activity under low or no oxygen. In contrast to aerobic lagoons, anaerobic systems are deeper and require much less surface area. They also have the ability to handle much higher organic loads (1). Sludge build-up in anaerobic lagoons is much less than for aerobic ones: for each kg of BOD_5 destroyed by the anaerobic process, only about 0.1 kg of sludge is produced as compared to 0.5 kg for an aerobic system. The major disadvantage of an anaerobic lagoon is that it can produce strong odours unless the sulphate level in the leachate is maintained well below 100 mg/L.

Applicability and efficiency

- Used for leachate, non-halogenated solvents, halogenated organics, PCBs, oily waste, certain biomedical wastes, fuel wastes and other organics wastes.
- Most appropriate for relative small volumes of high-COD (chemical oxygen demand) wastes.

Advantages

- Maintenance costs are minimal.
- Relatively high solids content in the waste can be accommodated.

Limitations

- Slow-rate degradation, requiring long hydraulic retention time.
- Requires large surface of land.
- Anaerobic lagoon tends to produce strong odours which need to be controlled or treated.

Cost evaluation

Waste stabilization ponds with a capacity of 2,000 tonnes/year would have an operating cost of $42/tonne of wastewater (2) in 1994 dollars.

Approval requirements

Recommended loadings for aerated lagoons are less than 0.05 kg BOD_5/m^3/day and results in 0.5 kg sludge per kg BOD^5 removed (1).

References

1. MOEE, 1995. Treatment technologies for landfill leachates. ISBN 0-7778-3731-5. PIBS 3332E. January 1995.

2. A.D. Little, 1986. Technologies and systems for treatment and disposal of special wastes in Ontario. Final report to Ontario Waste Management Corporation, by Arthur D. Little of Canada Limited, October 2, 1986.

5.7 WETLANDS

Process summary

Natural and artificial swamp areas can be used to biologically treat organic wastes and adsorb inorganics out of a waste stream.

Process description

Wetlands are defined as lands which are inundated or saturated with surface water or groundwater long enough each year to maintain saturated soil conditions (1). These areas are usually capable of supporting the growth of typical vegetation (cattails, bulrushes, reeds, grasses, trees and shrubs) and aquatic life. There are often referred to as swamps, marsh, bogs, etc.

Various designs are used in the treatment of wastewater by wetlands:

a) constructed wetlands
b) surface flow (SF) system
c) subsurface flow (SSF) system
d) reed bed treatment system.

Constructed wetlands are a designed complex of saturated substrates, emergent and submergent vegetation, animal life and water that simulate natural wetlands. The principal components are:

a) supporting beds with various rates of hydraulic conductivity
b) plants thriving in water-saturated and anaerobic conditions
c) water circulation system (water flowing in or above the surface of the substrate)
d) animal population (invertebrates and vertebrates)
e) aerobic and anaerobic bacterial population.

The surface flow (SF) system consists of basins with clay bottom or liner to prevent seepage. The basin is filled with soil or other suitable medium to support emergent vegetation. Wastewater flows at relatively shallow depth over the soil surface. The presence of plant stalks or debris helps to prevent short-circuiting.

The subsurface flow (SSF) system consists of a lined trench filled with gravel or rock media. Placed on top of this gravel bed is a layer of soil to support a growth of emergent vegetation with an extensive root system. The system is built with a slight slope from the inlet to outlet of 0.5 to 3%. The leachate flows horizontally through gravel bed into the rhizosphere (root area) of the wetland plants. During its passage through the rhizosphere, the wastewater is treated by filtration, sorption, precipitation and microbial degradation.

The reed bed treatment (RBT) system is a modification of the SSF design. It contains reeds growing in a bed of larger sized gravel. The major difference is that the flow rate of the leachate is faster in the RBT system.The key features of the systems are:

a) rhizomes of reeds grow vertically and horizontally opening up the soil to provide a hydraulic pathway;
b) treatment is accomplished by bacterial activity (aerobically in the rhizosphere and anaerobically in the surrounding soil);
c) oxygen is transferred to root area by the plants;
d) suspended solids in the leachate are biodegraded in the above ground layer along with debris of dead leaves and stems.

Applicability and efficiency

- Used for leachate, non-halogenated solvents, halogenated organics, oily waste, fuel wastes and other organics wastes.

Advantages

- Low capital and maintenance costs.
- No mechanical or electrical equipment required.

Limitations

- Efficiency dependant on temperature.
- Accumulation of metals and clogging of substrates.
- Large land area required.
- Odours may be produced.

References

1. MOEE, 1995. Treatment technologies for landfill leachates. ISBN 0-7778-3731-5. PIBS 3332E. January 1995.

6. FIXATION/STABILIZATION TREATMENT PROCESSES

6.1 POZZOLANIC PROCESSES

Process summary

Sand or similar fine siliceous (pozzolanic) material and lime are mixed with the waste material which will form a concrete like mixture.

Process description

Waste fixation techniques rely on the reaction of lime with fine siliceous material (also referred to as pozzolanic) and water to produce a concrete like solid (pozzolanic concrete). The most common pozzolanic materials used in waste treatment are fly ash, ground blast furnace slag, and cement kiln dust. The use of these waste products to treat another waste is often advantageous to the generator who can treat two waste products at the same time (4).

Applicability and efficiency

- Particularly effective in stabilizing inorganic sludges and heavy metal hydroxide residues.
- Applicable to a wide range of hazardous wastes: inorganic residues containing heavy metals, waste mixtures containing low levels of organics and salts.
- Widest application in stabilization of flue gas cleaning residues from coal burning power plants.
- Long-term stability and resistance to leaching is good for some wastes, but is unknown for others (e.g. high organic wastes).

Advantages

- Raw materials usually non expensive (often considered wastes).

Limitations

- Interference with process: borates, sulphates and carbohydrates.
- Long-term leachability unknown with certain wastes (high organic content).

Cost evaluation

The capital cost for a treatment capacity of 70,000 tonnes/year is estimated at $833,000, based on a detailed study (1) done in 1985 and indexed to 1994 Canadian dollars. The operating costs, including materials ($2,815,000), electricity ($10,300), labour ($42,200), maintenance ($41,700) and other ($41,700), can be translated to approximately $40/tonne of waste treated (various solids and sludges).

Approval requirements

Treatment by solidification will generate approximately 1.6 tonne/tonne of solidified waste for landfilling (2).

Carbon adsorption will generally generate 100 kg/tonne of spent carbon, based on aqueous steams less than 10% organics. The carbon maybe suitable for regeneration or disposal as a solid waste or incineration (2).

References

1. A.D. Little, 1986. Technologies and systems for treatment and disposal of special wastes in Ontario. Final report to Ontario Waste Management Corporation, by Arthur D. Little of Canada Limited, October 2, 1986.

2. A.D. Little, 1985. Systems and technologies for treatment and disposal of special wastes in Ontario. Draft report to Ontario Waste Management Corporation, by Arthur D. Little of Canada Limited, February 8, 1985 (unpublished).

3. Freeman, H.M., 1989. Standard Handbook of Hazardous Waste Treatment and Disposal, McGraw-Hill, ISBN 0-07-022042-5.

4. Proctor & Redfern Limited, 1982. Generic process technologies study. Prepared for OWMC Environmental Assessment, Volume C2. Revised December 1982.

6.2 ENCAPSULATION

Process summary

The waste material is coated and encapsulated with a less toxic material in order to reduce the direct exposure of the waste material to the environment.

Process description

The process is also referred to as thermoplastic stabilization or encapsulation. Waste particulates are blent with bitumen (melted asphalt), paraffin or polyethylene materials. The waste may require pre-treatment, to ensure compatibility of the waste with the binder. The process requires specialized equipment to heat and mix the waste and the binding matrix.

Micro-encapsulation refers to the encapsulation of individual particles. Macro-encapsulation is the encapsulation of an agglomeration of waste particles (including drums, boxes, etc.).

Applicability and efficiency

- Applicable to wastes that are complex and difficult to treat.
- Primarily applicable to inorganic wastes.
- Efficiency of encapsulation is measured in terms of the leachability of the contaminants from the matrix, using various leaching tests (4,5).

Advantages

- Applicable to in-situ and ex-situ treatment.

Limitations

- Not applicable to wastes with high-water content, oxidizing contaminants, inorganic salts, or volatile organics with low molecular weights.
- Expensive process equipment and materials.
- Potential air pollution.

References

1. Freeman, H.M., 1989. Standard Handbook of Hazardous Waste Treatment and Disposal, McGraw-Hill, ISBN 0-07-022042-5.

2. Proctor & Redfern Limited, 1982. Generic process technologies study. Prepared for OWMC Environmental Assessment, Volume C2. Revised December 1982.

3. Environment Canada, 1990. Compendium of waste leaching tests. Report EPS 3/HA/7, May 1990.

4. Environment Canada, 1991. Proposed evaluation protocol for cement-based solidified wastes. Report EPS 3/HA/9, December 1991.

6.3 POLYMERIZATION

Process summary

The addition of a catalyst to a mixture of polymers and wastes causes the solidification of the polymers and encapsulation of the waste.

Process description

Organic polymers are initially mixed with the waste. The addition and mixing of a catalyst to the mixture causes polymerization (solidification) of the polymers and produces a solid resin-waste mixture. The most thoroughly tested organic polymer solidification process is the urea-formaldehyde (UF) system (2).

Applicability and efficiency

- Applicable to organics, including aromatics, aliphatics and oxygenated monomers (styrene, vinyl chloride, etc).
- Used on spills.

Advantages

- Detoxification of toxic organics into less toxic ones.

Limitations

- Limited to specific type of organics.

References

1. Freeman, H.M., 1989. Standard Handbook of Hazardous Waste Treatment and Disposal, McGraw-Hill, ISBN 0-07-022042-5.

2. Proctor & Redfern Limited, 1982. Generic process technologies study. Prepared for OWMC Environmental Assessment, Volume C2. Revised December 1982.

6.4 VITRIFICATION

Process summary

The waste material is mixed with silica and heated by passing a large electrical current in the mixture, creating a mass of waste encapsulated in glass.

Process description

For in-situ applications, electrical electrodes are inserted into the contaminated solid, usually soil, and an electrical current is passed through the material. The resultant high temperature melts the mixture of silica (naturally present in the soil) and waste. The material then cools, resulting in a glassy type material encapsulating the contaminants. A variation of this process for ex-situ applications is to add the waste to a liquid bath of glass which vaporizes the organics and some of the inorganics. The remaining inorganics are incorporated into the glass.

The process is also referred to as molten-glass process or glassification technique (1,2).

Applicability and efficiency

- Proven technology for treating highly radioactive wastes.
- Produce a high degree of waste containment.

Advantages

- Effective in-situ treatment.

Limitations

- Organics, and some metals, are volatilized and escape from the waste, requiring capture and treatment of the gases.
- High energy (electricity) requirement.

References

1. Freeman, H.M., 1989. Standard Handbook of Hazardous Waste Treatment and Disposal, McGraw-Hill, ISBN 0-07-022042-5.

2. Proctor & Redfern Limited, 1982. Generic process technologies study. Prepared for OWMC Environmental Assessment, Volume C2. Revised December 1982.

7. MISCELLANEOUS TREATMENT PROCESSES

7.1 DEEP WELL INJECTION

Process summary

Liquid hazardous wastes are injected deep underground into an area where the waste will not reappear near the surface nor will it affect the environment.

Process description

Deep well injection involves the disposal of pumpable wastes below the ground to depths ranging from 300 to 3,600 meters. Wastes are usually pretreated to remove large solids that could clog the injection pumps. The raw or pretreated wastes are pumped into the pores of deep permeable subsurface strata, and local geological factors determine pumping depths and characteristics (4).

Applicability and efficiency

- Used for acids, alkalis, aqueous salts, non-halogenated spent solvents, halogenated organics, PCBs, and other organic wastes.
- In Ontario, the Cambrian formation is believed to be the only suitable site for possible siting of deep well injection. In Alberta, this technology is presently used at the Alberta Special Wastes Treatment Centre near Swan Hills (250 NW of Edmonton).

Advantages

- Relatively inexpensive storage process.
- Proven effective technology, used over 30 years in the oil and gas industries.

Limitations

- Site must be assessed and selected carefully.
- Monitoring of the site for potential migration is usually required.

Cost evaluation

The capital cost for a disposal capacity of 21,000 tonnes/year is estimated at \$3,700,000, based on a detailed study (3) done in 1985 and indexed to 1994 Canadian dollars. The operating costs, including electricity (\$12,000), labour (\$42,200), maintenance (\$184,300) and other (\$184,300), can be translated to approximately \$20/tonne of waste treated (various aqueous solutions).

Approval requirement

The approval will require a thorough review of the information on the geological and groundwater characteristics of the well sites.

Reference

1. Freeman, H.M., 1989. Standard Handbook of Hazardous Waste Treatment and Disposal, McGraw-Hill, ISBN 0-07-022042-5.

2. A.D. Little, 1986. Technologies and systems for treatment and disposal of special wastes in Ontario. Final report to Ontario Waste Management Corporation, by Arthur D. Little of Canada Limited, October 2, 1986.

3. A.D. Little, 1985. Systems and technologies for treatment and disposal of special wastes in Ontario. Draft report to Ontario Waste Management Corporation, by Arthur D. Little of Canada Limited, February 8, 1985 (unpublished).

4. Proctor & Redfern Limited, 1982. Generic process technologies study. Prepared for OWMC Environmental Assessment, Volume C2. Revised December 1982.

7.2 GEOLOGIC ISOLATION

Process summary

Wastes are stored permanently in abandoned or closed underground mines.

Process description

Geologic isolation involves placing special wastes in abandoned or newly constructed mines designed to receive and store the wastes indefinitely. Wastes are stacked in containers in the open areas left by room and pillar construction in the mining operation (1).

In the design and evaluation of the geologic isolation site, considerations should include (2):

1) Types of mines: rock types mines such as salt, potash, gypsum, limestone and underground granite mines are suitable.
2) Depth: near-surface mines often have fractures in the roof allowing for water infiltration. For deep mines (up to 1,000 m), stability and access can be a problem.
3) Layout and access: room and pillar configuration is most suitable
4) Safety: spill cleanup and emergency exit are important provisions.
5) Ventilation: intake of fresh air and exhaust/treatment of stale air are in important considerations, specially during the handling of hazardous wastes.

Applicability and efficiency

- Salt caverns in the Sarnia region serve as repository for heavy chlorinated hydrocarbons and waste purge gas from a gas-processing plant.
- Used for halogenated organics, PCBs, oily waste, fuel wastes and other organic wastes.

Advantages

- Provide storage safer than surface storage for wastes that cannot be treated.

Limitations

- Not suitable for liquid and ignitable wastes.
- Restricted to wastes that cannot be adequately treated by other technologies.

Cost evaluation

The cost evaluation is based on a capacity plant of 50,000 tonnes/yr. The operating cost is estimated at $210 per tonne (1994 dollars) (1).

References

1. A.D. Little, 1986. Technologies and systems for treatment and disposal of special wastes in Ontario. Final report to Ontario Waste Management Corporation, by Arthur D. Little of Canada Limited, October 2, 1986.

2. Freeman, H.M., 1989. Standard Handbook of Hazardous Waste Treatment and Disposal, McGraw-Hill, ISBN 0-07-022042-5.

7.3 ABOVE GROUND STORAGE

Process summary

Wastes are stored temporally in specially designed warehouses or permanently in underdrained, above ground storage mounds.

Process description

Warehouse storage involves the disposal of containerized wastes in specially designed above ground buildings. Treated or solidified wastes are placed in drums which are stacked on pallets in warehouse rooms.

Design for above ground storage mounds is similar to municipal landfill design (4).

Applicability and efficiency

- Used for acids, alkalis, aqueous salts, other inorganics, non-halogenated solvents, halogenated organics, PCBs, oily waste, certain biomedical wastes, fuel wastes and other organics wastes.

Advantages

- Allows for better selection or development of suitable technologies for hazardous waste treatment.

Limitations

- Warehouse storage increases risk for environmental contamination by spills, fires and natural disasters.
- Warehouse storage is very costly and requires regular monitoring and maintenance.

Cost evaluation

For a warehouse storage capacity of 50,000 tonnes, the operating cost is evaluated at $250/tonne (1994 dollars). Additional costs are expected for perpetual care (1).

References

1. A.D. Little, 1986. Technologies and systems for treatment and disposal of special wastes in Ontario. Final report to Ontario Waste Management Corporation, by Arthur D. Little of Canada Limited, October 2, 1986.

2. Freeman, H.M., 1989. Standard Handbook of Hazardous Waste Treatment and Disposal, McGraw-Hill, ISBN 0-07-022042-5.

3. Proctor & Redfern Limited, 1982. Generic process technologies study. Prepared for OWMC Environmental Assessment, Volume C2. Revised December 1982.

4. MOEE, 1993. Guidance manual for landfill sites receiving municipal waste. PIBS 2741. ISBN 0-7778-2074-9. November 1993.

APPENDIX A
APPLICATION OF WASTE TREATMENT TECHNOLOGIES FOR INORGANIC WASTES

TECHNOLOGY Physical Processes	ACIDS	ALKALIS	AQUEOUS SALTS	LEACHATE	OTHER INORGANICS
Adsorption				X	
Air Flotation					X
Air Stripping				X	
Autoclaving					
Centrifugation					X
Chelation	X	X	X	X	
Distillation					
Electrodialysis			X		
Emulsion Breaking					
Evaporation	X	X	X	X	X
Filtration					X
Freeze Crystallization	X	X	X		
Heavy Media Separation					X
Ion Exchange	X	X	X	X	X
Irradiation				X	
Liquid/Liquid Extraction					
Oil/Water Separation					
Reverse Osmosis/Ultrafiltration			X	X	
Screening					X
Sedimentation					X
Solvent Extraction					
Steam Stripping				X	
Supercritical Extraction					

TECHNOLOGY Chemical Processes	ACIDS	ALKALIS	AQUEOUS SALTS	LEACHATE	OTHER INORGANICS
Alkali Metal Dechlorination					
Alkaline Chlorination			X		
Catalytic Dehydrochlorination					
Chemical Oxidation				X	
Chemical Precipitation			X	X	X
Chemical Reduction				X	
Hydrolysis					
Electrolytic Oxidation			X		
Neutralization	X	X	X	X	

TECHNOLOGY Biological Processes	ACIDS	ALKALIS	AQUEOUS SALTS	LEACHATE	OTHER INORGANICS
Activated Sludge				X	
Anaerobic Digestion				X	X
Biological Adsorption			X	X	
Fixed Bed Reactor				X	
Fluidized Bed Reactor				X	
Land Treatment				X	
Waste Stabilization Lagoon				X	
Wet Lands				X	

TECHNOLOGY Fixation/Stabilization Processes:	**ACIDS**	**ALKALIS**	**AQUEOUS SALTS**	**LEACHATE**	**OTHER INORGANICS**
Pozzolanic Processes			X		X
Encapsulation					X
Polymerization					
Sorption				X	
Vitrification					X

TECHNOLOGY	**ACIDS**	**ALKALIS**	**AQUEOUS SALTS**	**LEACHATE**	**OTHER INORGANICS**
Miscellaneous Processes:					
Deep-well Injection	X	X	X		
Isolation					
Storage	X	X	X		X

APPENDIX B
APPLICATION OF WASTE TREATMENT TECHNOLOGIES FOR ORGANIC WASTES

TECHNOLOGY Physical Processes	NON-HAL SPENT SOLVENTS	HAL. ORGANIC	PCBs	OILY WASTE	BIO-MEDI. WAS.	OTHER ORGANIC WASTE	FUEL WASTE
Adsorption	X	X	X			X	
Air Flotation				X			X
Air Stripping	X	X				X	X
Autoclaving					X		
Centrifugation				X			
Chelation							
Distillation	X	X	X	X		X	X
Electrodialysis							
Emulsion Breaking				X			X
Evaporation	X	X				X	
Filtration							
Freeze Crystallization	X	X			X	X	
Heavy Media Separation							
Ion Exchange							
Irradiation	X	X	X		X		
Liquid/Liquid Extraction	X	X				X	
Oil/Water Separation				X			X
Reverse Osmosis/ Ultrafiltration	X	X				X	
Screening							
Sedimentation				X			X
Soil Washing	X	X	X	X		X	X
Solvent Extraction	X	X				X	
Steam Stripping	X	X				X	
Supercritical Extraction	X	X	X			X	

TECHNOLOGY Chemical Processes	NON-HAL SPENT SOLVENTS	HAL. ORGANIC	PCBs	OILY WASTE	BIO-MED. WAS.	OTHER ORGANIC WASTES	FUEL WASTES
Alkali Metal Dechlorination		X	X				
Alkaline Chlorination							
Catalytic Dehydrochlorination		X	X				
Chemical Oxidation	X	X		X		X	X
Chemical Precipitation							
Chemical Reduction	X	X	X	X		X	X
Hydrolysis	X	X				X	
Electrolytic Oxidation							
Neutralization	X	X				X	

TECHNOLOGY Biological Processes	NON-HAL. SPENT SOLVENTS	HAL. ORGANICS	PCBs	OILY WASTE	BIO-MED. WAS.	OTHER ORGANIC WASTES	FUEL WASTES
Activated Sludge	X	X	X	X	X	X	X
Anaerobic Digestion	X	X	X	X	X	X	X
Biological Adsorption							
Fixed Bed Reactor	X	X	X	X	X	X	X
Fluidized Bed Reactor	X	X	X	X	X	X	X
Land Treatment	X	X		X		X	X
Waste Stabilization Lagoon	X	X	X	X	X	X	X
Wet Lands	X	X		X		X	X

HAL. is for Halogenated.

TECHNOLOGY Fixation/ Stabilization Processes	NON-HAL. SPENT SOLVENTS	HAL. ORGANICS	PCBs	OILY WASTE	BIO-MED. WAS.	OTHER ORGANIC WASTES	FUEL WASTES
Pozzolanic Processes							
Encapsulation				X			X
Polymerization	X					X	
Sorption	X	X		X		X	X
Vitrification							

TECHNOLOGY Miscellaneous Processes	NON-HAL SPENT SOLVENTS	HAL ORGANICS	PCBS	OILY WASTE	BIO-MED. WAS.	OTHER ORGANIC WASTES	FUEL WASTES
Deep-well Injection	X	X	X			X	
Isolation	X	X	X	X		X	X
Storage	X	X	X	X	X	X	X